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USAF FLYING QUALITIES REQUIREMENTS
FOR A STOL TRANSPORT

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AMST FLIGHT SYSTEMS GROUP
AMST SYSTEM PROGRAM OFFICE

MAY 1979

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AERONAUTICAL SYSTEMS DIVISION
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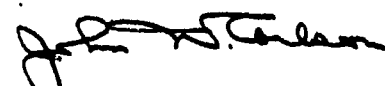
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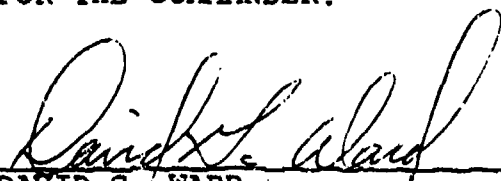
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The USAF flying qualities requirements for the Advanced Medium STOL Transport (AMST) are presented. These requirements were intended for a production version of the AMST, and were released as part of the USAF Proposal Instruction Package in 1977. The requirements of the general military specification, "Flying Qualities of Piloted Airplanes" (MIL-F-8785B) were modified to account for STOL flight characteristics; specific (continued on next page)			

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design features of the two AMST prototype airplanes (YC-14 and YC-15); to make the flying qualities requirements compatible with the general military specification for flight control systems (MIL-F-9490D); and to abide by the directives of the AMST System Program Office. The rationale for the modifications are discussed. Examples of the modifications are as follows: (a) the minimum service speed for landing was not permitted to be less than the speed at which the rolling moments due to an engine failure could be controlled; (b) the airplane velocity and flight path responses were to be decoupled during flight on the backside of the power required curve; (c) the flight path change capability required for STOL landings was addressed; and (d) a wind model that accounted for shear effects was incorporated.

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FOREWORD

This report presents the USAF flying qualities requirements for the Advanced Medium STOL Transport (AMST). These requirements were developed by the Flight Systems Group, AMST System Program Office, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio under project number 1226. The project engineer for this effort was Mr. Gary J. Gerken, and the work was performed from May 1976 through March 1977.

This report was submitted by the author during December 1978.

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TABLE OF CONTENTS

	Page
SECTION 1 INTRODUCTION	1
1.1 Background	1
1.2 Modification Procedure	2
SECTION 2 REQUIREMENT CHANGES AND RATIONALE	3
2.1 1.4 Flight Phase Categories	3
2.2 2. Applicable Documents	4
2.3 3.1.6.2 Airplane Failure States	4
2.4 3.1.7 Operational Flight Envelopes	5
2.5 3.1.7.2 Minimum Operational Speed	5
2.6 3.1.7.4 Operational Load Factor	7
2.7 3.1.8.1 Maximum Service Speed	7
2.8 3.1.8.2 Minimum Service Speed	8
2.9 3.1.8.4 Service Load Factor	9
2.10 3.1.9.1 Maximum Permissible Speed	10
2.11 3.1.9.2 Minimum Permissible Speed (Vs)	10
2.12 3.1.10.2 Requirements for Airplane Failure States	12
2.13 3.1.10.2.1 Requirements for Specific Failures	15
2.14 3.1.10.3.2 When Levels Are Not Specified	16
2.15 3.1.12 Assault Mode of Operation	17
2.16 3.2 Longitudinal Flying Qualities	17
2.17 3.2.1.1 Longitudinal States Stability	17
2.18 3.2.1.2 Phugoid Stability	18
2.19 3.2.1.3 Hands On Flight - Path Stability	18
2.20 3.2.1.3.1 Hands Off Flight - Path Stability	20
2.21 3.2.1.4 Pitch Attitude Versus Flight Path Angle	20

	TABLE OF CONTENTS (CONTINUED)	Page
2.22	3.2.1.5 Velocity Change Versus Flight Path Angle	21
2.23	3.2.2.1 Longitudinal Response	21
2.24	3.2.2.1.1 Short-Term Frequency and Acceleration Sensitivity	2
2.25	3.2.2.1.2 Total System Damping	26
2.26	3.2.2.1.3 Residual Oscillations	26
2.27	3.2.2.1.4 Flight Path Response	28
2.28	3.2.2.2 Control Feel and Stability in Maneuvering Flight	28
2.29	3.2.2.2.1 Control Forces in Maneuvering Flight	29
2.30	3.2.3.2 Longitudinal Control in Maneuvering Flight	31
2.31	3.2.3.2.1 Flight Path Angle Change Capability Required for Landing on Tactical Mobility Mission Runway (Paragraph 3.2.1.1 of the System Specification)	32
2.32	3.2.3.2.1.a Landing in Turbulence	34
2.33	3.2.3.2.2 Turn Rate	35
2.34	3.2.3.3 Longitudinal Control in Takeoff	35
2.35	3.2.3.4 Longitudinal Control in Landing	36
2.36	3.2.3.4.2 Landing Control Power	36
2.37	3.2.3.4.3 Pitch Acceleration	36
2.38	3.2.3.5 Longitudinal Control Forces in Dives—Service Flight Envelope	37
2.39	3.2.4 Pitch Attitude Command	37
2.40	3.2.5 Airspeed Command and Hold Modes	38
2.41	3.2.6 Pitch Rate Command Mode	38
2.42	3.2.7 Pitch Hold Mode	39
2.43	3.3.1 Lateral-Directional Mode Characteristics	40
2.44	3.3.1.2 Roll Mode	40

	TABLE OF CONTENTS (CONTINUED)	Page
2.45	3.3.1.3 Spiral Stability	42
2.46	3.3.1.4 Coupled Roll-Spiral Oscillation	42
2.47	3.3.2.2 Roll Rate Oscillation	42
2.48	3.3.2.2.1 Additional Roll Rate Requirements for Small Inputs	43
2.49	3.3.2.4.1 Additional Sideslip Requirements for Small Inputs	43
2.50	3.3.2.5.1 Lateral Acceleration Limits, Rolling	43
2.51	3.3.2.6 Turn Coordination	44
2.52	3.3.2.7 Residual Oscillations	44
2.53	3.3.4 Roll Control Effectiveness	44
2.54	3.3.4.3 Linearity of Roll Response	46
2.55	3.3.4.5 Rudder-Pedal Induced Rolls	46
2.56	3.3.5.3 Yaw Control	46
2.57	3.3.5.4 Yaw Control Linearity and Sensitivity	47
2.58	3.3.5.5 Heading Control	47
2.59	3.3.6 Lateral-Directional Characteristics in Steady Sideslips	47
2.60	3.3.6.3 Rolling Moments in Steady Sideslips	48
2.61	3.3.7 Lateral Directional Control in Crosswinds	48
2.62	3.3.7.1 Final Approach in Crosswinds	49
2.63	3.3.9.1 Thrust Loss During Takeoff Run	49
2.64	3.3.9.2 Thrust Loss After Takeoff	50
2.65	3.3.10 Roll Attitude Command	51
2.66	3.4.1 Dangerous Flight Conditions	52
2.67	3.4.2.1 Stalls	52
2.68	3.4.2.1.1 Stall Approach	52
2.69	3.4.2.1.2 Stall Characteristics	53
2.70	3.4.2.1.3 Stall Prevention and Recovery	54

	TABLE OF CONTENTS (CONTINUED)	Page
2.71	3.4.2.2.2 Recovery from Post-Stall Gyrations and Spins	54
2.72	3.5 Characteristics of the Manual Flight Control System (MFCS)	54
2.73	3.5.2.1 Control Centering and Breakout Forces	55
2.74	3.5.2.3 Rate of Control Displacement	56
2.75	3.5.3 Dynamic Characteristics	56
2.76	3.5.3.2 Damping	57
2.77	3.5.4.1 Performance of Augmentation Systems	57
2.78	3.5.4.2 Saturation of Augmentation Systems	57
2.79	3.5.5 Failures	58
2.80	3.5.5.1 Failure Transients	58
2.81	3.5.6.1 Transients	59
2.82	3.6.3.1 Pitch Trim Changes	59
2.83	3.6.5 Delete	63
2.84	3.7 Atmospheric Environment	63
SECTION 3	CONCLUSIONS AND RECOMMENDATIONS	65
APPENDIX		67
REFERENCES		152

LIST OF SYMBOLS

SYMBOL	DEFINITION	UNITS
AEO	All Engines Operating	---
AFFDL	Air Force Flight Dynamics Laboratory	---
AFFTC	Air Force Flight Test Center	---
AMST	Advanced Medium STOL Transport	---
ARC	Ames Research Center	---
B-1	Bomber Aircraft	---
\bar{c}	Mean Aerodynamic Chord	ft
CEI	Critical Engine Inoperative	---
cg	Center of gravity (% of \bar{c})	---
CTOL	Conventional Takeoff and Landing	---
C-1XA	Generalized Designation for AMST	---
DLC	Direct Lift Control	---
ENFTC	Flight Stability and Control Branch	---
FCS	Flight Control System	---
F_s	Stick Force	---
g	Acceleration of gravity	ft/sec ²
MAC	Military Airlift Command	---
n	Load Factor	---
SP \bar{O}	System Program Office	---
SST	Supersonic Transport	---
STOL	Short Takeoff and Landing	---
T	Thrust	lb
u	Perturbation velocity	kts
USAF	United States Air Force	---

LIST OF SYMBOLS
(continued)

SYMBOL	DEFINITION	UNITS
V	Airspeed	kts
V _s	Stall Speed	kts
GREEK CHARACTERS		
α	Angle of Attack	deg
β	Sideslip Angle	deg
γ	Flight path angle	deg
Δ	Indicates Change in Value	---
δ^*	Control surface deflection angle	deg
	*e - elevator *Flap - flap deflection *s - control stick displacement *Slat - slat deflection *w - pilot's control wheel	
ζ	Damping ratio	---
θ	Pitch attitude	deg
σ	Damping ($\zeta\omega$)	1/sec
τ_R	Roll mode time constant	sec
τ_ψ	Heading response time delay	sec
ϕ	Bank angle	deg
ψ	Heading angle	deg
ω	Frequency	rad/sec

SECTION I

INTRODUCTION

1.1 BACKGROUND

The Advanced Medium STOL Transport (AMST) flying quality requirements are documented in this report, as well as the rationale for them. These requirements were included in the Proposal Instruction Package released on 16 September 1977, and were intended as requirements for a production AMST. The general requirements of the military specification, Flying Qualities of Piloted Airplanes (reference 1), were not directly applicable to the AMST and required modification. One reason for this was that the AMST was designed to fly frequently on the back side of the power required curve at a lower dynamic pressure ($q=25 \text{ lb/ft}^2$) than conventional airplanes. The general requirements of Reference 1 were also modified to address the specific design approaches taken by the two AMST prototype contractors, McDonnell Douglas Corporation (YC-15) and the Boeing Aerospace Company (YC-14). Prototype flight test further determined areas of conflict with Reference 1, such that where the flight test results were acceptable, the general specification requirements were modified. Requirements and terminology of Reference 1 were also changed to be compatible with the military specification for Flight Control Systems (Reference 2). Procuring activity management direction also resulted in changes to the general requirements of Reference 1. These directives were as follows:

- a. A specification states the required system performance; not design solutions.
- b. Procuring activity approval of a design approach was eliminated in order to give the contractor design flexibility to meet the required performance.
- c. Tiering of specifications was prohibited. That is, a specification could not be invoked simply by referencing it in another. The intent of this requirement was to prevent needless, contradictory or redundant requirements for the AMST. Requirements could be extracted from any specification or an entire specification used if it were applicable to the AMST.
- d. The contractor was required to prepare a detailed Quality Assurance section for each specification; therefore, no detailed guidance was given the contractors on how each requirement of a specification was to be verified.

The decision was made early in the development of the AMST

flying qualities requirements to modify Reference 1 for both conventional and STOL flight. The military specification, Flying Qualities of Piloted V/STOL Aircraft (Reference 3), did not adequately address STOL flying qualities and was more applicable to VTOL than STOL airplanes. The modification of Reference 1 to address STOL was not as complex as it may seem. Many of the same considerations are present for both conventional and STOL flight, such as flight envelopes, failure states, and flight control system response characteristics. Where specific STOL requirements were needed, they were stated in an appropriate section of Reference 1 either by incorporating into an existing requirement or by adding a new paragraph number. During the modification of Reference 1, the original paragraph numbers and subjects remained unchanged to allow easy comparison between the AMST requirements and the general specification. Note that in the AMST specification the acronym STOL was not used due to the lack of a universal definition. STOL has been defined in the past in terms of airspeed, dynamic pressure, percent powered lift, field length, approach flight path angle, etc., but no universal agreement on a definition has been reached.

1.2 MODIFICATION PROCEDURE

The Aeronautical Systems Division, specifically the AMST Flight Systems Group and the Flight Stability and Control Branch (ENFTC) had the responsibility to define the USAF flying quality requirements for the AMST. A review was first conducted of STOL simulation reports, analytical studies, limited flight experience and proposed STOL flying quality criteria. Based on this information, a general understanding of STOL flying qualities was obtained, particularly in areas that differed greatly from conventional flight characteristics. Reference 1 was then reviewed to determine if the requirements were adequate, needed to be revised, or if a new requirement had to be added to account for STOL characteristics. Five draft specifications were prepared between May 1976 and March 1977. Comments on these draft versions were obtained from the AMST contractors, the Air Force Flight Dynamics Laboratory (AFFDL), the NASA Ames Research Center, and the Air Force Flight Test Center (AFFTC). Coordination was also performed in-house to ensure that flight control, performance, structures and other personnel were provided an opportunity to comment on requirements which affected their disciplines. The various drafts were revised based on the comments received until the final AMST flying quality requirements were released on 14 September 1977. A copy of these requirements is presented in the appendix.

The next section of this report will present the major AMST requirements changes from Reference 1 and the rationale for the changes. Section 3 presents the conclusions and recommendations resulting from the preparation of AMST flying qualities requirements.

SECTION 2

REQUIREMENTS CHANGES AND RATIONALE

This section presents the major AMST requirements changes from the general military specification, Flying Qualities of Piloted Airplanes (Reference 1). Complete AMST requirements including paragraph numbers, titles and wording, are presented below and are followed by a discussion of the rationale for the requirements. Only the final versions of the AMST requirements are presented below, and no effort was made to follow the evolution of the requirements through the five drafts. Note that the symbol C-1XA was used to denote the AMST for proposal instruction purposes, and is used in the requirements below.

2.1 1.4 Flight Phase Categories. The Flight Phases have been combined into three categories which are referred to in the requirements statements. These Flight Phases shall be considered in the context of total missions so that there will be no gap between successive Phases of any flight and so that transition will be smooth. In certain cases, requirements are directed at specific Flight Phases identified in the requirement. When no Flight Phase or Category is stated in a requirement, that requirement shall apply to all three categories. Flight Phases descriptive of the C-1XA are:

Nonterminal Flight Phases:

Category A - Those nonterminal Flight Phases that require rapid maneuvering, precision tracking, or precise flight-path control. Included in this Category are:

- a. Low Altitude Aerial Delivery (LA).
- b. Close Formation Flying (FF).
- c. Contour Flying (CF).
- d. In-flight Refueling (receiver) (RR).

Contour flying involves flight at altitudes up to 1000 feet above ground level to avoid ground fire or detection.

Category B - Those nonterminal Flight Phases that are normally accomplished using gradual maneuvers and without precision tracking, although accurate flight-path control may be required. Included in this Category are:

- | | |
|----------------|-------------------------|
| a. Climb (CL) | d. Descent (D) |
| b. Cruise (CR) | e. Deceleration (DE) |
| c. Loiter (LO) | f. Aerial Delivery (AD) |

Terminal Flight Phases:

Category C - Terminal Flight Phases normally requiring accurate flight path control.

- | | |
|-------------------------|-------------------------|
| a. Assault Takeoff (AT) | d. Go-around (GA) |
| b. Takeoff (TO) | e. Assault Landing (AL) |
| c. Approach (PA) | f. Landing (L) |

The word assault in this document is meant to signify that engine failed safety margins are not provided.

Discussion: This paragraph follows the general specification closely although some explanation of the flight phases is needed. For Category A, the Low Altitude Aerial Delivery flight phase relates to the Low Altitude Parachute Extraction System (LAPES) maneuver. The Category B flight phases of Descent and Deceleration are also intended to account for Emergency Descent and Emergency Deceleration. For Category C, the Takeoff and Landing flight phases include STOL Takeoff and STOL Landing. Assault Takeoff and Assault Landing are an effort to define the maximum capability of a STOL airplane by not providing engine out safety margins. The Assault Flight phases are considered to be a fallout of the design and probably would only be used under wartime situations. As implied above, various airplane configurations can exist for a particular flight phase, and the contractor must define these as required by paragraph 3.1.5, Configurations.

2.2 2. Applicable Documents. Deleted.

Discussion: Applicable documents were deleted since procuring activity policy prohibited one specification invoking other specifications. The intent of this policy was to prevent "blanket" application of a specification without a thorough review of its requirements. Appropriate requirements of the listed specifications in the general MIL-F-8785B (Reference 1) could have been retained if desired after a review. However, it was concluded that appropriate AMST personnel associated with the listed specifications were to review their requirements and no need was seen to duplicate their efforts. The only exception to this was the specification Stall/Post-Stall/Spin Flight Test Demonstration Requirements for Airplanes, MIL-S-83691, which was reviewed. It was concluded that the general MIL-F-8785B specification requirements were adequate, and that MIL-S-83691 would be used for guidance when it came time for the procuring activity to approve the contractor proposed flight test conditions to be used for stall testing.

2.3 3.1.6.2 Airplane Failure States. The contractor shall define and tabulate all Airplane Failure States which consist

of failures of airplane components or systems that affect the Flying Qualities of the airplane. Failure States caused by more than three independent subsystem failures need not be tabulated. Airplane Failure States shall reflect changes in airplane hardware or the results of more detailed analyses. Examples would be jammed surfaces, mechanical or electrical disconnects, one or more channels of augmentation failed, and/or two hydraulic systems out. Other degradations or failure of airplane components for systems resulting from the first failure must also be accounted for in determining the total effects on aircraft control. More specific direction is given in 3.1.10.2.

3.1.6.2.1 Airplane Special Failure States. Certain components, systems or combinations thereof may have extremely remote probability of failure during a given mission. These failure probabilities may, in turn, be very difficult to predict with any degree of accuracy. Special Failure States of this type need not be considered in complying with the requirements of Section 3 (except 3.1.10.2) if justification for considering the Failure States as special is submitted by the contractor. The Airplane Special Failure States shall reflect changes in airplane hardware or the results of more detailed analyses. Failures which have a probability of occurrence less than 1×10^{-9} per mission may be considered Special Failure States without submittal to the procuring activity.

Discussion: The wording changes for these paragraphs were to clarify what failures were to be defined and to limit the amount of paperwork required by the contractor. The paperwork was reduced by limiting the failures to be tabulated and submitted to those caused by three independent subsystem failures and by defining a special failure state as one having a probability of failure less than 1×10^{-9} per mission.

2.4 3.1.7 Operational Flight Envelopes. The Operational Flight Envelopes define the boundaries in terms of speed, altitude, and load factor within which the airplane must be capable of operating in order to accomplish the missions of 3.1.1. These envelopes shall be defined for the atmospheric temperatures required by paragraph 3.2 of the System Specification and Appendix 50 of the System Specification. Envelopes for each applicable Flight Phase shall be established by the contractor. The boundaries of the Operational Flight Envelopes shall be as defined by paragraphs 3.1.7.1, 3.1.7.2, 3.1.7.3, and 3.1.7.4.

Discussion: The above paragraph was changed to require that the envelopes be defined for standard and hot day temperatures. This was significant since STOL stall speeds depend heavily on thrust available, and thrust available is dependent upon temperature. Paragraphs 3.1.8 Service Flight Envelopes and 3.1.9 Permissible Flight Envelopes were modified similarly.

2.7 3.1.7.2 Minimum Operational Speed. The minimum operational

speed (V_{min}) shall be low enough that the operational missions and performance requirements of the System Specification can be achieved. The minimum operational speeds shall not be greater than those shown in Table I for each Flight Phase. In addition, it must be possible for the airplane to encounter a 20 knot upgust at the selected minimum operational speed without exceeding the stall angle of attack (α_s), with all engines operating. For the critical engine inoperative, the requirement is to penetrate a 15 knot upgust. Trim control settings shall not be changed by the crew for these gust encounters.

TABLE I. Upper Limits for Minimum Operational Speeds

Flight Phase Category	Flight Phase	V_{min}
A	Low Altitude Aerial Delivery (LA) Close Formation Flying (FF) Contour Flying (CF) In-flight Refueling (receiver) (RR)	# 1.6 V_s 1.6 V_s 1.6 V_s
B	Climb (CL) Cruise (CR) Loiter (LO) Descent (D) Deceleration (DE) Aerial Delivery (AD)	0.85 $V_{r/c}$ 0.85 V_{range} 0.85 V_{end} 1.4 V_s 1.4 V_s 1.2 V_s
C	Assault Takeoff (AT) Takeoff (TO) Approach (PA) Go-around (GA) Assault Landing (AL) Landing (L)	* 1.2 V_s 1.2 V_s 1.2 V_s * 1.2 V_s

The minimum speed for zero degrees deck angle minus 10 knots, but not less than 1.2 V_s .

* The minimum speeds for these Flight Phases should be defined by the contractor.

Discussion: Specific guidance was provided the contractors as to the minimum operational speeds required. The Category A minimum speed of 1.6 V_s was based mainly on the desire to make the AMST compatible with the lower speeds encountered in the KC-135 refueling envelope. The speed was also chosen to be compatible with the roll requirements of 3.3.4. That is, no reason could be

determined for having the minimum operational speed lower than 1.6Vs, and the 1.6Vs speed made the roll requirements reasonably obtainable.

The gust encounter requirements were based on Reference 3, and the intent was to provide the STOL airplane with the capability to penetrate the same gusts usually encountered by conventional airplanes. Since the STOL airplane approaches at a lower airspeed than a conventional airplane, the angle of attack margin to stall must be larger than that normally provided. The gust magnitude was reduced with an engine failure because the probability of having an engine failure and encountering the higher gust was considered small. Thus, the gust magnitude was reduced to make it a more reasonable probability of occurrence.

2.6 3.1.7.4 Operational Load Factors. The maximum (minimum) operational load factor is the lowest (highest) algebraically of the following:

- a. $n = 2.0$ ($n = 0.5$).
- b. The load factor at which stall warning occurs.

The maximum and minimum operational load factors for each Flight Phase shall be established as a function of speed for several different altitudes.

Discussion: The operational load factor limits were selected based on what were considered to be required for the operational missions. Load factor limits higher than those selected were discussed but design penalties were probable at the limits of the airspeed-load factor (V-g) envelopes. The penalties mentioned most often were a complex stick force versus elevator deflection gearing to meet the stick force per g linearity requirement, and sizing the roll control surfaces to meet the roll requirements.

2.7 3.1.8.1 Maximum Service Speed. The maximum service speed, V_{max} or M_{max} , for each altitude shall be the same as the maximum operational speed. An acceptable speed margin shall exist between the maximum service speed and the maximum permissible speed, with the highlift devices stored, to allow for inadvertent overspeed conditions. When the high-lift devices are extended, the maximum service speed may be the same as the maximum permissible speed.

Discussion: In general, the AMST prototype maximum speeds were defined arbitrarily by the contractors with only the cruise Mach number and altitude defined by the procuring activity. The contractors added an arbitrary incremental Mach number to the cruise Mach number, which then defined the constant altitude

maximum speed (V_H). It was intended by the above requirement that both the operational and service maximum speeds be V_H . The thrust required to attain V_H was less than that available in many cases and thus V_H could be exceeded at constant altitude by adding power. The contractors added an overspeed margin to V_H that resulted in a limit speed (V_L). The maximum permissible speed was intended to be V_L . It was felt that the margin for overspeed conditions should be 0.05 Mach or the increase in speed obtained during a 7.5 degrees dive held for 20 seconds and then recovered at 1.5g's, whichever is greater. The latter requirement was based on FAR Part 25, Section 25.335(b)(1). These were not specified in 3.1.8.1 due to an incomplete understanding of the impact they would have on the separate contractors. The two definitions are considered reasonable for defining the overspeed margin. For the high-lift devices extended case, no speed margin was required since the FAA does not require a margin nor could the need for one be established. Refer to FAR Part 25, Section 25.333.

The above requirement differs from the general MIL-F-8785B (Reference 1) in that the general specification would allow the maximum service speed to be the same as the maximum permissible speed. This was not considered safe, and it was required that an acceptable speed margin be provided as stated above. The general MIL-F-8785B, part "c", may have required a speed margin, but the intent of that part of the requirement was not clear.

2.8 3.1.8.2 Minimum Service Speed. The minimum service speed, V_{min} or M_{min} , for each altitude is the highest of:

- a. $1.1V_S$
- b. $V_S + 10$ knots equivalent airspeed.
- c. Stall warning speed defined by 3.4.2.1.1, for any thrust setting.
- d. A speed at which it is possible to achieve a constant heading following a sudden asymmetric loss of takeoff thrust from the most critical factor, and thereafter to maintain a constant heading. No changes in the pilot selected configuration are allowed to show compliance with this requirement. In addition, at this speed, the roll control capability shall provide at least 30 degrees bank angle change in four seconds. The roll requirement shall be met for the steady state asymmetric thrust condition with takeoff thrust maintained on the operative engine(s) and trim at normal settings for symmetric thrust. The airplane may be banked up to five degrees in a direction to assist control.
- e. A speed limited by reduced visibility or an extreme pitch attitude that would result in the tail or aft fuselage contacting the ground.

Discussion: The AMST minimum service speed definition differs in four major respects with the general MIL-F-8785B (Reference 1). First, the MIL-F-8785B, part c, was deleted. Part c allowed a minimum speed where full airplane nose up elevator control power and trim were required to maintain straight, steady flight. NASA Ames Research Center stated that this condition was more appropriate to a Permissible Envelope limit, and AMST personnel concurred. Second, part d of MIL-F-8785B, which defined the minimum speed as that at which level flight could be maintained with Military Rated Thrust, was deleted. The reason for this was that an airplane in the STOL landing configuration may not have sufficient thrust to fly level, and no justification could be determined for requiring that it fly level. Third, para c of the AMST requirement does not allow the minimum service speed to be less than the speed at which stall warning occurs for either unaccelerated or accelerated stalls. This was an addition and the intent was to prohibit stall warning within the Service Flight Envelope. Lastly, a minimum air control speed requirement was added to ensure that the STOL airplane on landing would have sufficient lateral control with an engine failed. For the STOL airplane, an engine failure results in a large lift loss which induces a large rolling moment which must be controlled. The roll control capability of 30 degrees bank angle change in four seconds was required to provide the capability to control the dynamics of the engine failure, and then after the failure any roll upsets due to turbulence or winds. This roll capability was intended to be demonstrated both into and away from the failed engine.

2.9 3.1.8.4 Service Load Factors. Maximum and minimum service load factors, $n(+)$ [$n(-)$], shall be established as a function of speed for several significant altitudes and weights. No consideration is given to the power required to maintain flight at these g levels. The maximum (minimum) service load factor, when trimmed for lg flight at a particular speed and altitude, is the lowest (highest) algebraically of:

- a. The positive structural limit load factor, or for negative load factor to zero g's.
- b. The load factor corresponding to stall warning (3.4.2.1.1).
- c. A safe margin below (above) the load factor at which intolerable buffet or structural vibration is encountered.

Discussion: The second sentence above was added with the intent to clarify that 3.1.8.4 was addressing instantaneous load factor capability and not sustained load factor. Sustained load factor would necessitate an increase in thrust in order to hold

airspeed, altitude and load factor. Part a of the AMST requirement limits the negative load factor to zero g's. This was considered adequate for mission flexibility and reduced flight test verification of requirements since the service envelope was reduced. Part c of the general MIL-F-8785B (Reference 1) was deleted for the reason stated in 2.8 for part c.

2.10 3.1.9.1 Maximum Permissible Speed. The maximum permissible speed for each altitude shall be the lowest:

- a. Limit speed based on structural considerations.
- b. Limit speed based on engine considerations.
- c. The speed at which intolerable buffet or structural vibrations is encountered.
- d. The speed at which the transonic Mach tuck is greater than allowed for Level 3 of paragraph 3.2.1.1.1.

Discussion: Two differences exist between the above requirement and the general MIL-F-8785B (Reference 1). The intent and meaning of part d of the general MIL-F-8785B requirement were not clear; therefore, it was deleted. Part d of the above AMST requirement allows the permissible envelope to be limited by Mach tuck. This was added so that adequate flying qualities would not have to be provided out to the structural airplane limits, since there were no operational or safety considerations to do so. As discussed in 2.7, the maximum permissible speed was intended to be the limit speed, V_L , which accounted for overspeed conditions from the maximum service speed.

2.11 3.1.9.2 Minimum Permissible Speed(V_S). The minimum permissible speed for a specified configuration shall be the highest of:

- a. Speed with constant heading angle for flight at CL_{max} (the first local maximum of the lift coefficient vs angle of attack which occurs as CL is increased from zero).
- b. Speed at which uncontrollable pitching, rolling, or yawing occurs; i.e., loss of control about a single axis.
- c. Minimum demonstrated speed due to intolerable buffet, structural vibration, angle of attack effects, or an excessive rate of sink.

The minimum permissible speed shall be determined for:

- a. $1g$ normal to the flight path.

b. Approach to stall at 1/2 knot to 1 knot per second.

c. Most unfavorable center of gravity.

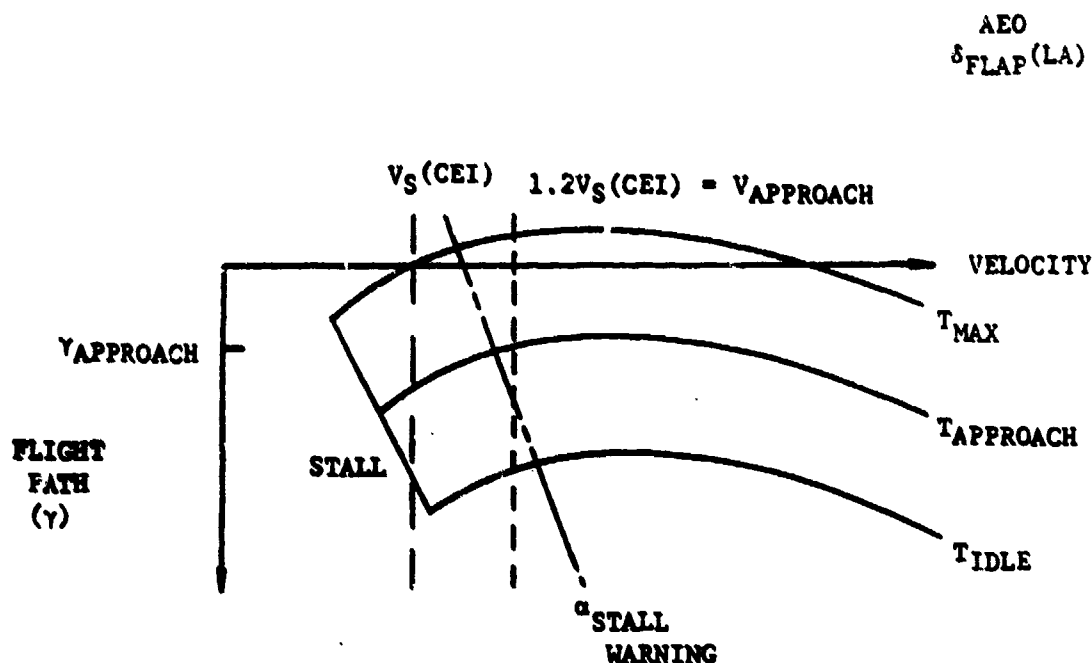
d. Out of ground effect.

e. The following condition that results in the highest minimum permissible speed for each flight phase. Assault takeoff and assault landing are excluded from this consideration.

<u>Flight Phase</u>	<u>Thrust Control Setting</u>	<u>All Engines Operating (AEO)/ Critical Engine Inoperative (CEI)</u>
Takeoff	Takeoff	AEO and CEI
Approach/Landing	Takeoff	CEI
Approach/Landing	Approach	AEO
Go-Around	Go-Around	AEO and CEI
Descent/Deceleration	Minimum Allowable*	AEO and CEI
All Other	T/LF at 1.2 V_S	AEO and CEI

*Minimum allowable includes reverse thrust.

Discussion: The minimum permissible speed (V_S) definition has a direct impact on airplane design (e.g., sizing lateral control surfaces to balance airplane at stall with the critical engine inoperative). The definition and table above are similar to those in paragraphs 6.2.2 and 3.1.9.2.1 of the general MIL-F-8785B (Reference 1). Several items should be clarified. First, the contractor does not need procuring activity approval in order to limit V_S based on angle of attack effects, rate of sink, and so forth. The contractor is required to meet the performance requirements and this will ensure that an acceptable V_S is selected. Second, the stall speed of a STOL airplane in the Landing configuration is a function of thrust, so that for every thrust setting there is a different stall speed. The approach taken in the AMST requirement for the Landing Flight Phase was to select the higher stall speed resulting from two cases: either all engines operating (AEO) with approach power, or critical engine inoperative (CEI) with takeoff power. This stall speed would then be used to determine the normal approach speed ($1.2V_S$ for both AEO and CEI with any thrust setting. Protection from encountering stall for low power settings was provided by a stall warning system. These points are illustrated on the following figure where V_S for this example was based on CEI and takeoff power.



The NASA proposed three criteria for minimum operational landing speeds in Reference 5. Summarized, they are as follows:

- a. $1.15 V_S$
or
 $V_S + 10 \text{ Kts}$ AEO with approach power
- b. $1.3 V_S$
 $V_S + 20 \text{ Kts}$ AEO with takeoff power
- c. $1.1 V_S$
 $V_S + 10 \text{ Kts}$ CEI with approach power.

The AMST requirement is $1.2 V_S$ with V_S determined with either AEO and approach power or CEI and takeoff power. This results in a minimum operational speed 4-5 knots greater than the critical case suggested by NASA for the STOL landing. The manner in which the AMST minimum operational speed requirement is written (see 2.5) allows the contractor to use a speed margin less than 20 percent; however, Level 1 flying qualities must be demonstrated at this lower speed. This would also include encountering the gusts defined in 2.5.

The other flight phase conditions stated in paragraph 3.1.9.2 were a consensus of the critical conditions for determining stall speeds. Again, the intent was to arrive at one stall speed for each flight phase in order to ease the piloting task. It was not desired that pilots be required to remember different stall speeds for each thrust and engine operating condition.

2.12 3.1.10.2 Requirements for Airplane Failure States. When Airplane Failure States exist (3.1.6.2), a degradation in flying qualities is permitted. The contractor shall determine, based on

the most accurate available data, the probability of occurrence of each Airplane Failure State per mission and the effect of the Failure State on the flying qualities within the Operational and Service Envelope. Specifically, the analysis shall address the following: (a) The Wartime - Logistics Resupply - Airland Profile defined in the System Specification, Appendix 60, paragraph 4.3, Table 60.4 shall be used for this analysis. This mission scenario will be used to determine how long specific aircraft systems are used per mission. (b) All of the various elements that can fail in many different modes but result in the same general airplane condition shall be tabulated under one general failure state (e.g., pitch augmentation failure, force gradient reduction, one hydraulic system out, etc.). The probability of encountering the general failure state shall be calculated as a function of all the element failures. Once the effect of a general failure state on handling qualities is determined (See part c), the probability of encountering a particular level of handling qualities is also known for a particular general failure state. (c) The effect of a general failure state on handling qualities in calm air must be determined by either analytical comparison of the degraded performance with quantitative requirements stated herein or pilot opinion from simulation studies investigating a particular failure(s). (d) The probability per mission of encountering Level 2 shall include the probability of all the general failure states in which the Flying Qualities are worse than Level 2. (e) The probability per mission of encountering Level 3 shall include the probability of all the general failure states in which the Flying Qualities are worse than Level 3 and are unsafe. (f) The probability of encountering Flying Qualities Levels 2 or 3 shall include the special failure states, if the probability can be calculated. (g) Each general failure state is assumed to be present at whichever point in the flight envelope that is most critical from a handling qualities point of view. (h) Random failures which result in Level 3 or below flying qualities at the altitudes and airspeeds of the missions of System Specification, Appendix 60, shall be assumed to result in mission abort. These aborts shall be included in the C-1XA mission reliability analysis. (i) Encountering below Level 3 flying qualities will be assumed to be a safety consideration and shall be included in the C-1XA mission safety analysis.

The probabilities of encountering lower levels of flying qualities due to failures shall be less than the values shown in Table III.

TABLE III. Levels for Airplane Failure States

Probability of Encountering	Within Operational Flight Envelope	Within Service Flight Envelope
Level 2 After Failure	10^{-2} per mission	
Level 3 After Failure	10^{-4} per mission	10^{-2} per mission

In no case shall a Failure State, except an approved Special Failure State, degrade any flying quality parameter outside the Level 3 limit. All flight control system failure states that result in below Level 3 Flying Qualities shall not have a cumulative failure probability of greater than 5×10^{-7} per mission. These failure states are excluded from the requirement to be submitted to the procuring activity.

Discussion: The above requirement is considered one of the primary requirements in the AMST specification and one of the most difficult to make meaningful and enforceable. The requirement is important since it allows flying qualities to degrade due to failures and attempts to limit how often that may occur. One of the major difficulties with probability numbers is that small changes in assumptions can result in large changes in probability numbers. Further, design approaches can result in better probability numbers but a corresponding decrease in safety. For example, by having only one control surface in a particular axis the probability of failure is reduced due to a smaller number of parts. However, aircraft control could be lost if the surface fails, which might not happen if two surfaces were used. Thus, a blind reliance on probability numbers may not give the desired result of a safe, reliable airplane. In the above requirement, an attempt is made to define the critical assumptions and the technique to be used to bookkeep the probabilities of failures and the effects from the failures. The above approach is patterned after that used on the B-1 bomber program (Reference 6).

Several items should be clarified in the requirement. First, the mission defined in the requirement was selected from five missions that were defined in the System Specification for calculation of mission completion success probabilities. Three of these five missions did not require STOL landings and consisted of two long range cargo delivery missions and one air-drop mission. The fourth mission was a resupply mission with one STOL landing and with a total flight time of approximately four hours. The mission selected for the Flying Qualities reliability analysis consisted of several landings, including three STOL landings, and best represented how the AMST would be used

in a war environment. The total flight time for the selected mission was approximately 10 hours. This mission time will make it difficult to meet the probability numbers of Table III since those numbers were based on a four hour mission time (Reference 14, page 45). This is illustrated by the following example. Assume that the mean time between failures that cause a degradation to Level 2 Flying Qualities is 500 flight hours. Thus, the probabilities of encountering Level 2 for a four hour and a ten hour mission are as follows:

$$4 \text{ hours: } P = 1 - e^{-4/500} = .0080$$

$$10 \text{ hours: } P = 1 - e^{-10/500} = .0198.$$

Second, compliance with the requirement was intended to be shown analytically in calm air. Extending the requirement to account for turbulent air was felt to be beyond the meaningful accuracy level of the analysis. Third, part h of the requirement was an attempt to relate a flying qualities Level 3 to a mission abort. The intent of part h was to evaluate random failures that occur during analytical mission reliability studies in terms of flying qualities. Missions would be aborted and tabulated as such if Level 3 flying qualities result at the point of the failure or at some other critical Mach/altitude point in the remainder of the mission. This differed from how the contractor would show compliance with the probability numbers of Table III. For Table III, the contractor would investigate the worst effect of a failure throughout the entire Operational envelope and the Service envelope, respectively. The reason this was not done for the mission reliability analysis was that it was considered overly stringent and would have had an unrealistic impact on mission reliability. Fourth, it was required that the probability of encountering Level 2 include the probability of encountering Levels of Flying Qualities worse than Level 2. A similar requirement was added for determining the probability of encountering Level 3. The reason for this method of calculation is that in theory an airplane state must pass through a better airplane state (e.g., Level 2) to get to a worse state (e.g., Level 3). In practice, this method of calculation does not change the probability numbers greatly since the probability of encountering a worse state (e.g., Level 3) is usually small compared to the probability of encountering the better state (e.g., Level 2). Lastly, a statement was added below Table III that all flight control system failure states that result in below Level 3 Flying Qualities shall not have a cumulative failure probability of greater than 5×10^{-7} per mission. This requirement was a restatement of one in the military specification for Flight Control Systems (Reference 2), paragraph 3.1.7. It was restated above to define failures that were not required to be submitted to the procuring activity in order to reduce paperwork.

2.13 3.1.10.2.1 Requirements for Specific Failures. Specific types of failures and the level of flying qualities that results in each Envelope from the failure are listed. These levels of flying qualities shall be met on the basis that the specific type of failure has occurred, regardless of its probability of occurrence. The listed failures shall be analyzed separately and with the failures occurring in-flight except for items 3 and 6. Possible crew corrective action may be initiated after an appropriate time delay.

Failure State	Flying Quality Level Within This Flight Envelope		
	Operational	Service	Permissible
1. Complete loss of Electronic Flight Control System (All electrical power failed).	3	3	-
2. Failure of most critical high lift surface to deploy or retract.	2	3	-
3. Takeoff with a flat tire.	2	3	-
4. Failure of in-flight deceleration device to deploy or retract.	2	3	-
5. Failures associated with rapid decompression.	3	-	-
6. Critical engine inoperative takeoff as defined in 3.2.1.5.2 of the System Specification.	2	3	-

Discussion: The specific failures listed above were defined, in general, by the Military Airlift Command (MAC), except for item 6 which was based on a System Specification requirement. The requirement is self-explanatory.

2.14 3.1.10.3.2 When Levels are not Specified. Deleted.

Discussion: Paragraph 3.1.10.3.2 was deleted in the AMST specification since it was considered a blanket requirement that could have major design impacts. The wording of the requirement was as follows:

"3.1.10.3.2 When Levels are not Specified. Within the Operational and Service Flight Envelopes, all requirements that are not identified with specific Levels shall be met under all conditions of component and system failure except approved Airplane Special Failure States (3.1.6.2.1)."

For example, 3.1.10.3.2 could have resulted in paragraph 3.3.9.1, "Thrust Loss During Takeoff Runs," requiring that the deviation of 30 feet from the runway centerline following an engine failure be met with hydraulic systems out or with a rudder hardover in a direction opposite to that required. Instead of using 3.1.10.3.2, all the AMST flying qualities requirements were reviewed and the required Levels defined where it was considered to be appropriate.

2.15 3.1.12 Assault Mode of Operation. Maximum use of power lift effects for airplane performance can be achieved by reducing the normal speed and control margins provided to account for failures. If this reduced margin region is utilized, a minimum of Level 2 handling qualities must be provided prior to failure occurrence.

Discussion: This requirement was added with the intent to allow the full capabilities of a STOL airplane to be used in a wartime environment. With reduced engine out control and speed margins, the STOL airplane could carry more weight into or out of a STOL field than it was designed for or land at shorter fields at a reduced landing speed with the same weight. If the contractor defines an assault mode of operation, then a minimum of Level 2 flying qualities must be provided.

2.16 3.2 Longitudinal Flying Qualities. Two primary longitudinal controllers are allowed. A third controller may be used if the pilot does not have to remove his hand(s) from the primary controller(s) to operate it. Contractor must define what primary airplane response is expected from each controller. If the response varies with airspeed, flap angle, etc., this must be defined.

Discussion: This requirement was based on NASA Ames Research Center studies which found that the pilot workload became unacceptable if three controllers were used continuously during a STOL landing. A third controller might be used to command flap angle or thrust vector. A controller such as a direct lift switch on the throttle would be acceptable as long as the pilot would not have to remove his hands from the throttles to operate it.

2.17 3.2.1.1 Longitudinal Static Stability. There shall be no tendency for the airspeed to diverge aperiodically when the airplane is disturbed from trim due to external disturbances with the cockpit controls fixed and with them free, except as allowed by 3.2.2.1.2. For airplane states that include automatic reduction of pilot control forces for steady state variations in speed or load factors, stable or neutral elevator control force and elevator control position with airspeed and load factor may be provided. The automatic reduction of forces shall not result in any reversal of the pilot's control force (i.e., from push to pull or vice versa).

For all other airplane states, this requirement will be considered satisfied if the variations of elevator control force and elevator control position with airspeed are smooth and the local gradients stable with: Trimmer and throttle controls not moved from the trim settings by the crew and 1g acceleration normal to the flight path and constant altitude over a range about the trim speed of +15 percent or +50 knots equivalent airspeed, whichever is less (except where limited by the boundaries of the Service Flight Envelope).

Stable gradients mean increasing pull forces and aft motion of the elevator control to maintain slower airspeeds and the opposite to maintain faster airspeeds. Neutral gradients mean zero pull forces and no motion of the elevator control to maintain slower or faster airspeeds. The term gradient does not include that portion of the control force or control positions versus airspeed curve within the preloaded breakout force or friction range.

Discussion: This requirement was modified from the general MIL-F-8785B (Reference 1) to address the control augmentation features of the AMST prototypes. These features were found to be acceptable based on prototype flight test experience. One part of the requirement is that the airspeed shall not diverge aperiodically due to external disturbances with or without an augmentation system functioning. This was to ensure that the airspeed would not diverge if the pilot's attention was distracted on another task. A limited relaxation in this requirement was allowed for landings or go-arounds under emergency conditions (see paragraph 3.2.2.1.2), but the pilot should be in the loop and alert under these unusual situations. A neutral stick force variation with airspeed or load factor due to automatic reduction of control forces was also allowed. This decision was based both on prototype flight test results and NASA Ames comments. The NASA found that neutral speed stability was preferable when maneuvering in pitch since the pilot did not have to retrim control forces. For that failure state and other airplane states as well, stable gradients of elevator control force and elevator control position with airspeed were required.

2.18 3.2.1.2 Phugoid Stability. The long period airspeed oscillations which occur when the airplane seeks a stabilized airspeed following a disturbance shall meet the requirements of paragraph 3.2.2.1.2.

Discussion: This requirement will be discussed under paragraph 3.2.2.1.2, paragraph 2.25.

2.19 3.2.1.3 Hands on Flight-Path Stability. Flight-path stability is defined in terms of flight-path-angle change where the airspeed is changed by the use of the elevator control only (throttle and flap setting not changed by either the crew or automatic devices). Specifically, this requirement is applicable

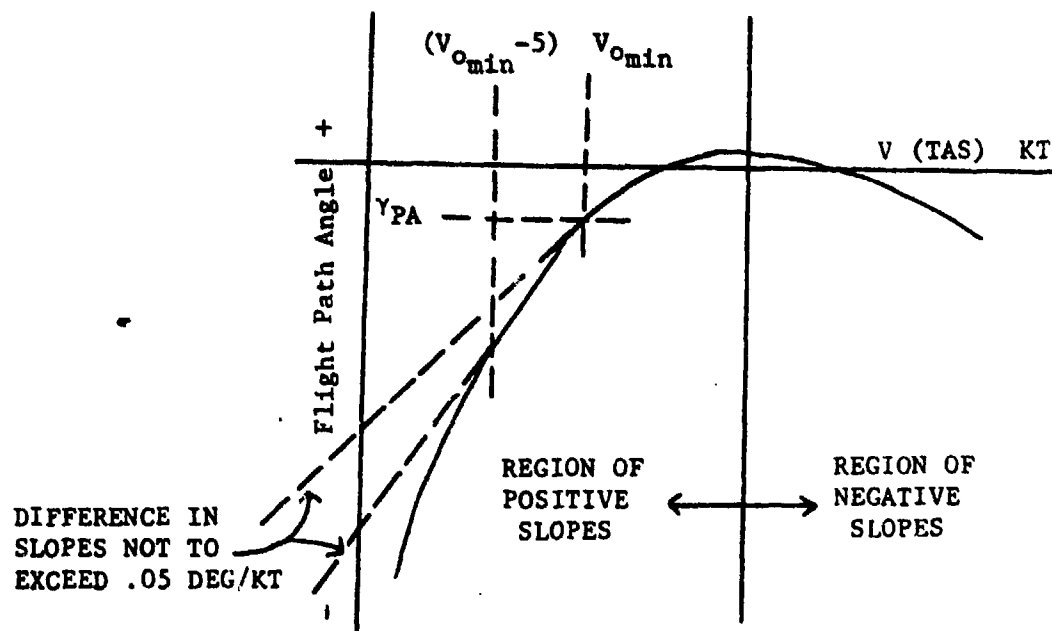
when an airspeed hold mode as defined in 3.2.5 is not functioning. Conversely, this requirement is not applicable when a speed hold mode is functioning. For the Landing Flight Phase and when the longitudinal column is used chiefly for rapid flight path control, the steady state flight-path-angle versus steady state true-airspeed curve shall have a local slope at V_{min} which is negative or less positive than:

- a. Level 1 ---- 0.06 degrees/knot
- b. Level 2 ---- 0.15 degrees/knot
- c. Level 3 ---- 0.24 degrees/knot

When a primary controller other than the longitudinal column is used to effect a rapid change in flight path, the local slope at V_{min} shall be negative or less positive than:

- a. Level 1 ---- 0.20 degrees/knot
- b. Levels 2 and 3 ---- 0.35 degrees/knot

In either case, the thrust setting shall be that required for the normal approach glide path at V_{min} . The slope of the flight-path angle versus airspeed curve at 5 knots slower than V_{min} shall not be more than 0.05 degrees per knot more positive than the slope at V_{min} , as illustrated by:



Discussion: There were three objectives in rewriting the above requirement. The first was to clarify that the requirement

did not apply when an airspeed hold mode was operating since $d\gamma/dV$ would approach infinity. That is, the flight path angle could be changed with little or no change in airspeed. Secondly, for conventional landings made using the column for flight path control, the $d\gamma/dV$ values of the general MIL-F-8785B (Reference 1) would apply. This requirement would apply to airplanes that were landed using the front-side control technique, regardless of whether or not the airplane used that control technique during STOL landings. The third objective was to address an airplane flown on the backside of the power required curve without an airspeed hold mode where the pilot must use thrust to control flight path. The second set of $d\gamma/dV$ values in the above requirement addresses that case. The Level 1 value was based on prototype flight test results, and the Level 2 and 3 value was based on SST simulation studies. NASA Ames studies have found that $d\gamma/dV$ was not a good flying qualities parameter for STOL airplanes. This was concluded since as long as the pilot had sufficient thrust and thrust response to control flight path, then the airplane could be operated at more positive values of $d\gamma/dV$ than allowed by the second set above. The listed $d\gamma/dV$ values were provided, however, since sufficient thrust or thrust response may not be available. The above requirement was a method of limiting the flight envelope to that which was felt to be reasonable.

2.20 3.2.1.3.1 Hands Off Flight-Path Stability. For Level 1, the airplane with cockpit controls free shall tend to return to the trimmed γ if it is perturbed from a trimmed flight condition by any momentary input other than commanded steady state changes in speed or flight path (γ).

Discussion: This requirement was taken from Reference 7, page 161, and the intent was to prevent the airplane from deviating from the trimmed flight path if left unattended by the pilot. A phugoid about the trimmed γ would be acceptable.

2.21 3.2.1.4 Pitch Attitude Versus Flight Path Angle. For the Landing Flight Phase, the ratio of the steady state attitude change to flight path angle change ($\Delta\theta/\Delta\gamma$) at constant airspeed for column inputs, for airplanes that use the longitudinal column for rapid flight path control, shall be as follows:

Level	$\Delta\theta/\Delta\gamma$	
	Min	Max
1	0.75	1.5
2	0.5	1.5

Discussion: This requirement was based on References 7 and 8. The intent was to ensure that a STOL airplane that uses the column to control flight path on the backside of the power required curve would respond in a conventional manner. That is, for an airplane flying on the frontside of the power required curve during a climb or descent at constant speed, the angle of attack is essentially constant. Hence, the following derivation indicates why a $\Delta\theta/\Delta\gamma$ of approximately one was required:

$$\theta = \gamma + \alpha$$

$$\frac{\partial\theta}{\partial\gamma} = \frac{\partial\gamma}{\partial\gamma} + \frac{\partial\alpha}{\partial\gamma} \quad \text{and since } \frac{\partial\alpha}{\partial\gamma} \text{ is essentially zero for}$$

$$\text{conventional response: } \frac{\partial\theta}{\partial\gamma} = \frac{\partial\gamma}{\partial\gamma} \quad \text{or} \quad \frac{\Delta\theta}{\Delta\gamma} = 1$$

The requirement implies that an airspeed hold mode is functioning in order to obtain the required $\Delta\theta/\Delta\gamma$ on the backside of the power required curve.

2.22 3.2.1.5 Velocity Change Versus Flight Path Angle. For the Landing Flight Phase with maximum flap deflection, the slope of the steady state velocity change to flight path angle change ($\Delta u/\Delta\gamma$), at constant pitch attitude, and with variation of thrust about the trim approach setting, shall be near the value of zero for Level 1 and 2. This requirement applies to airplanes that do not use the longitudinal column for rapid flight path control and at the minimum operational speed.

Discussion: This requirement was based on discussions of NASA Ames Research Center study results. The intent was that thrust changes would result mainly in a flight path response, and not airspeed changes. Sufficient data were not available to specify a quantitative requirement, but it was considered necessary to indicate the desire to decouple the airplane responses.

2.23 3.2.2.1 Longitudinal Response. Requirements for the responses of angle of attack, pitch rate, load factor, and airspeed which are produced by abrupt pilot inputs of the appropriate primary controller(s), are addressed by 3.2.2.1.1 and 3.2.2.1.2. These requirements apply with the cockpit controls fixed and with them free, after the input is made, for responses of any magnitude that might be experienced in normal service use. If oscillations are nonlinear with amplitude, the requirements shall apply to each cycle of the oscillation. For Normal States with a pitch attitude hold mode as defined in 3.2.7, these requirements do not apply when the airplane is within the static accuracy band of ± 0.5 degrees defined in 3.2.7.

Discussion: Several items need to be clarified in this introductory paragraph to 3.2.2.1.1 and 3.2.2.1.2. The term short period was not used since at the STOL flight conditions the roots of the characteristic equation may not be sufficiently separate to distinguish short period and phugoid motions. Damping and frequency requirements were specified not only for angle of attack but also pitch rate and load factor since with a highly augmented airplane their characteristic equations could be different. For an airplane that uses only elevator for pitch control, the characteristic equation for angle of attack, pitch rate and load factor should all be the same. For a STOL airplane, elevator, thrust and direct lift control (DLC) could result in different characteristic equations for each of the defined responses. The requirements were intended to apply only with the pilot in the loop (i.e., outside the static accuracy band of ± 0.5 degrees of the pitch attitude hold mode).

2.24 3.2.2.1.1 Short-Term Frequency and Acceleration Sensitivity. The short term natural frequency response of angle of attack, pitch rate and load factor at constant air-speed for the total airplane aerodynamics, flight controls, augmentation and propulsion system shall be similar to a second order response and shall be within the limits shown in Figures 1, 2, and 3. The Level 3 lower bounds on ω_{np} and η of Figure 3 may be relaxed if compliance is shown with the requirements of 3.2.2.1.4. Note that the n/a to show compliance with this requirement is due only to the movement of the longitudinal column.

Discussion: The intent of this requirement was that the contractor consider the short term response of the total airplane system. No quantitative definition of a similar second order response was given, and this was left open for resolution between the contractor and the procuring activity during the development of a production airplane. Consideration was given to using the complete Neal/Smith criterion for higher order systems, but it was considered best not to change design techniques midway in the AMST development program. The second order response assumption is usually critical in pitch, and a requirement addressing higher order systems should be developed for this axis. The lateral directional response was not as highly augmented as pitch, and therefore the utilization of a second order criterion was meaningful.

The Level 3 lower boundary for the short term natural frequency may be relaxed in the STOL region if acceptable load factor/flight path response can be obtained using the throttles. The short term frequency requirements of the general MIL-F-8785B (Reference 1) were intended to provide acceptable response time for load factor or flight path when controlled thru the longitudinal column. The n/a values with the short term

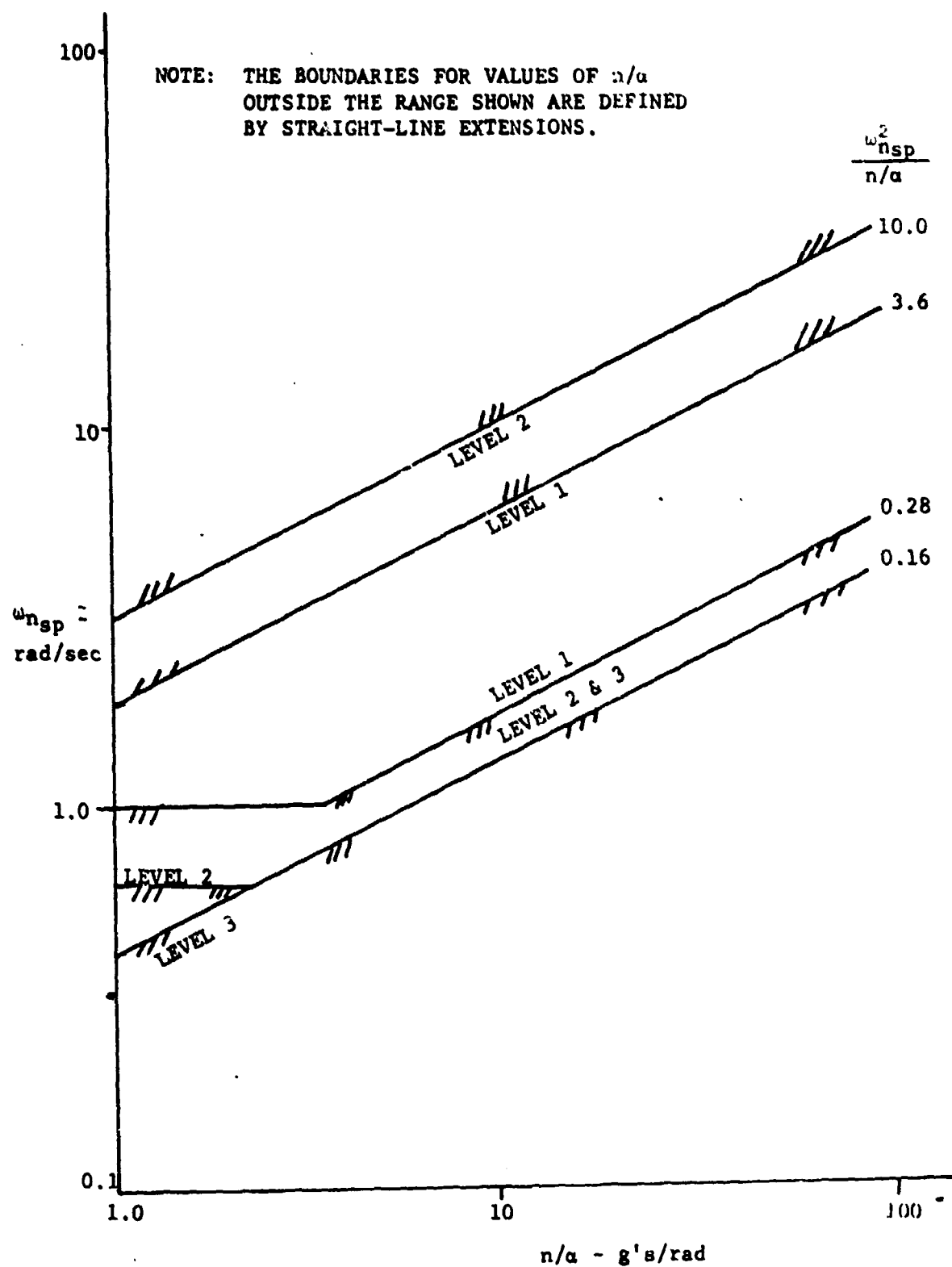


Figure 1. SHORT-TERM FREQUENCY REQUIREMENTS - CATEGORY A FLIGHT PHASES

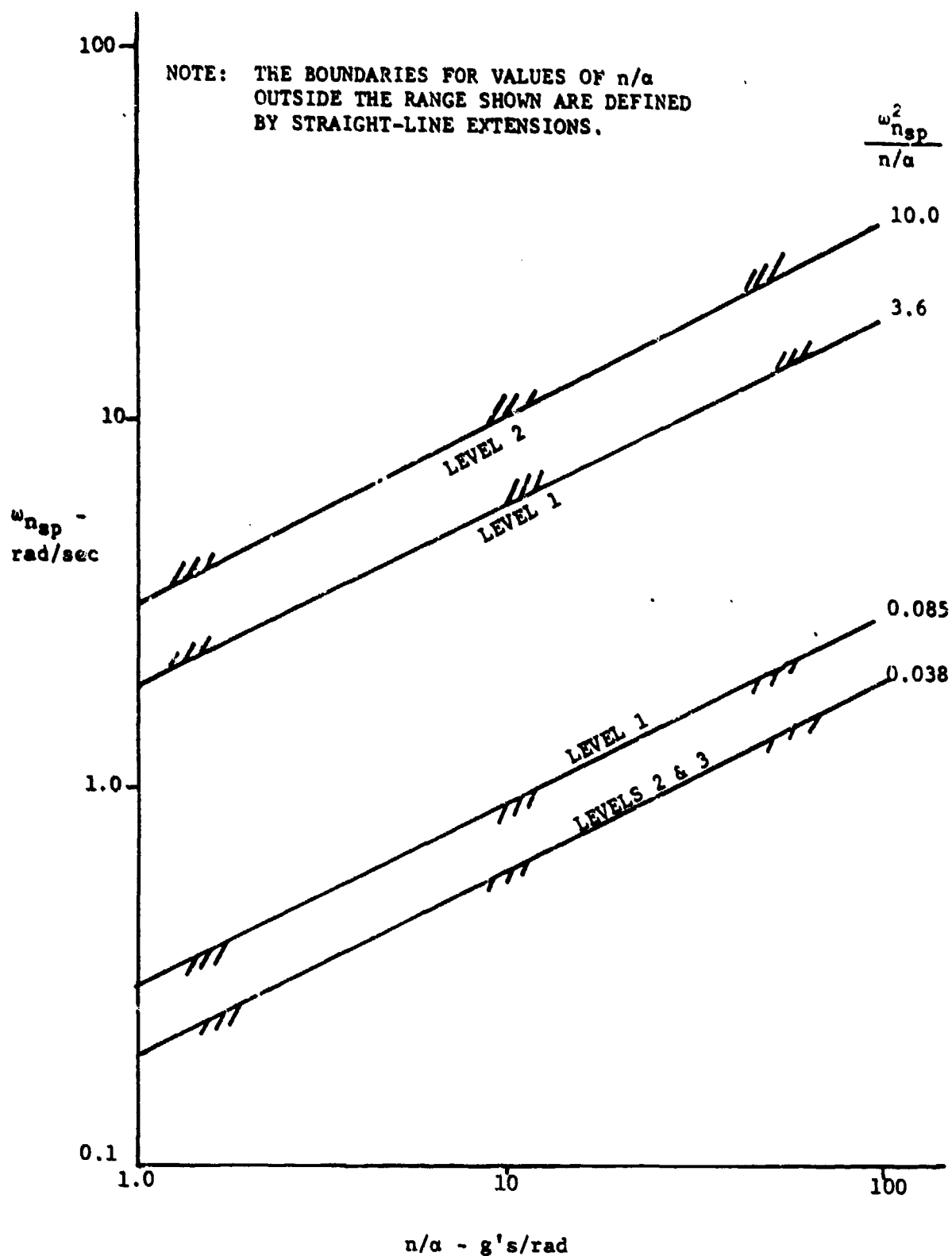


Figure 2. SHORT-PERIOD FREQUENCY REQUIREMENTS - CATEGORY B FLIGHT PHASES

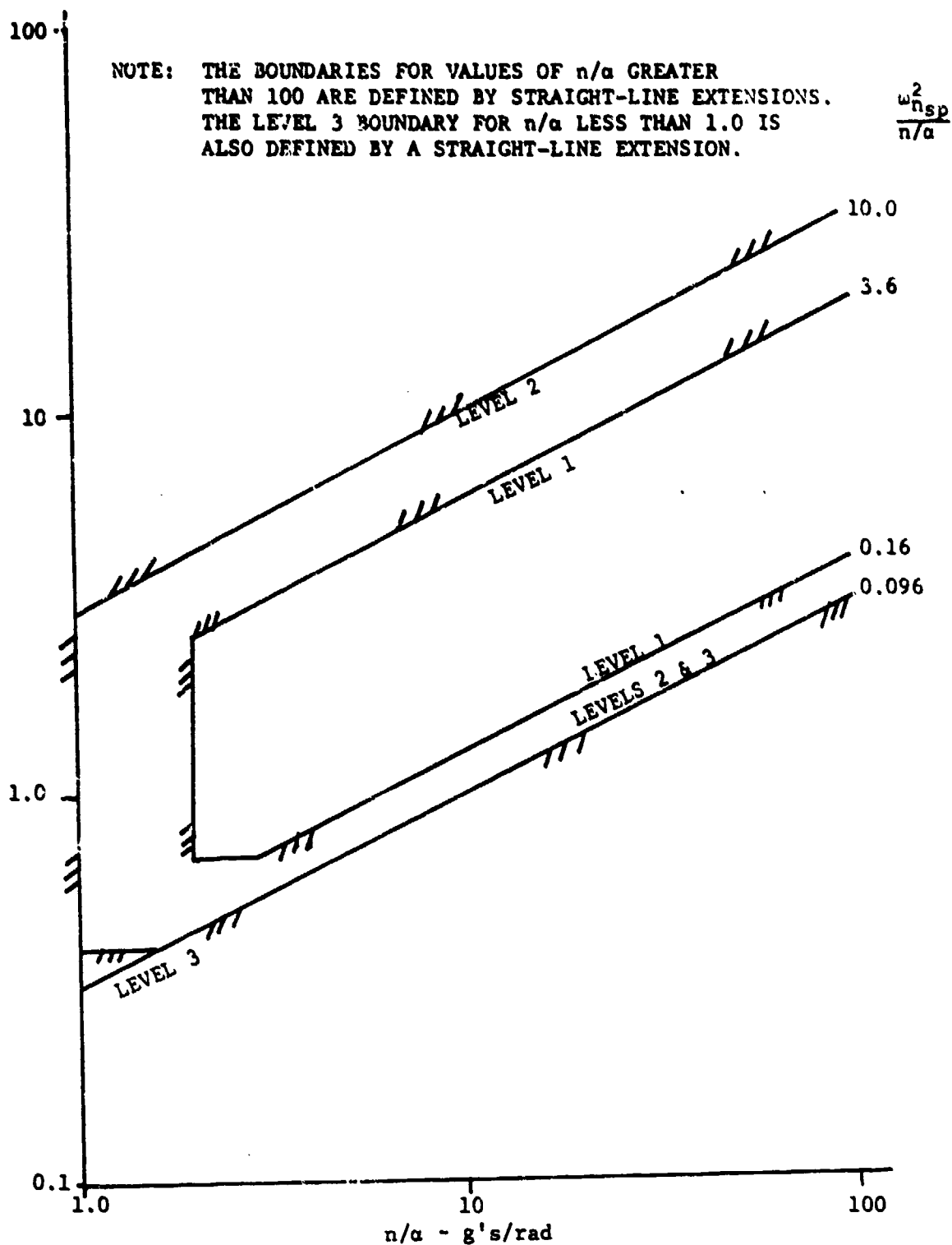


Figure 3. SHORT-PERIOD FREQUENCY REQUIREMENTS - CATEGORY C FLIGHT PHASES

natural frequency requirement would include the effects of direct lift and thrust if these are commanded via the longitudinal column.

2.25 3.2.2.1.2 Total System Damping. All longitudinal characteristic roots due to airplane aerodynamics, flight controls, augmentation, and propulsion system which affect angle of attack, pitch rate, load factor and airspeed response shall have damping that complies with Figure 4 for all Categories. The maximum damping ratio for the short term response shall be 1.3 and 2 for Levels 1 and 2, respectively. The Levels 2 and 3 requirements may be relaxed, as shown by the dashed lines on Figure 4, for cases where 3.2.1.1.1 permits relaxation of the static stability requirement (3.2.1.1) and for the Landing and Go-Around Flight Phases. In no case, however, shall the flight conditions that result in a characteristic root in this relaxed area be sustained for more than 5 minutes.

Discussion: The intent of Figure 4 was to address all characteristic equation roots regardless of the system order. The short term response roots must also meet the frequency requirements of 3.2.2.1.1. The Levels 1, 2, and 3 requirements apply for all Categories, and the solid lines of Figure 4 were based on the general MIL-F-8785B (Reference 1). The damped frequency of 0.3 rad/sec was selected based on AMST root locations as a reasonable boundary between short term and long term modes. The relaxed regions for Levels 2 and 3 were based on SST approach simulation studies (References 10 & 11) that indicated safe flying qualities were possible with root locations more unstable than allowed by Figure 4. Roots may be in the relaxed areas for only short periods of time to prevent high pilot workload or fatigue.

2.26 3.2.2.1.3 Residual Oscillations. Any sustained residual oscillations shall not interfere with the pilot's ability to perform the tasks required in service use of the airplane. For Levels 1 and 2, oscillations in normal acceleration at the pilot's station greater than ± 0.02 g's will be considered excessive for any flight phase.

Discussion: The ± 0.02 g's was selected to be consistent with paragraph 3.1.3.8 of the Flight Control System Specification (Reference 2) and because experience on the B-1 program indicated the ± 0.05 g's of the general MIL-F-8785B (Reference 1) was not satisfactory. The ± 3 mils pitch attitude oscillations requirement of the general MIL-F-8785B was deleted since there was little confidence in it and no justification for it could be found.

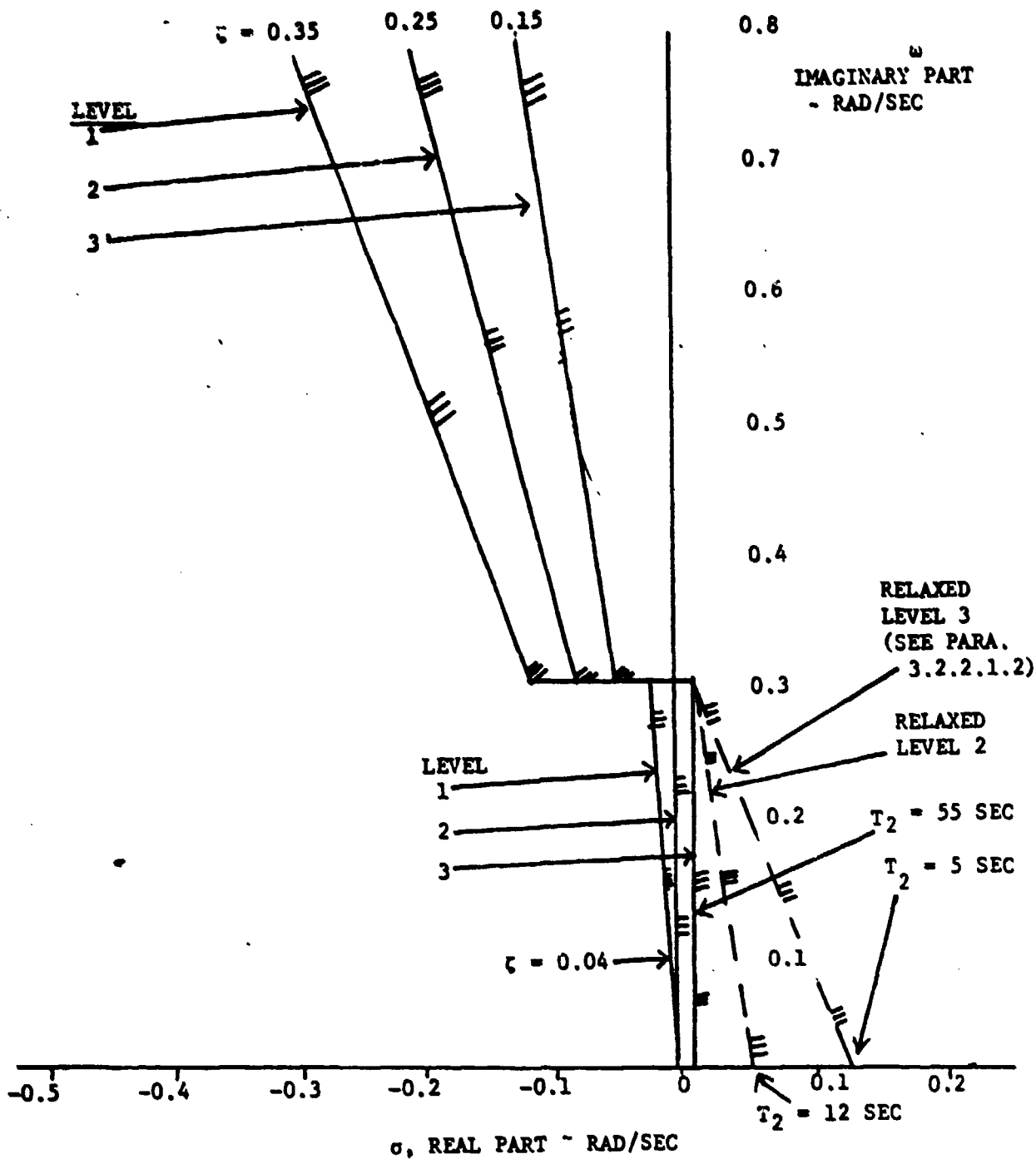
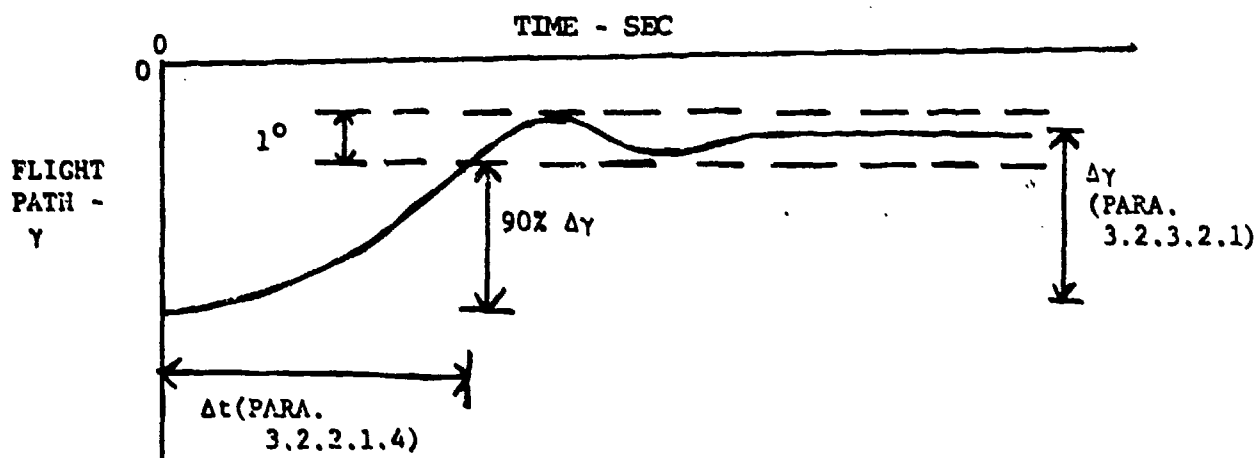


FIGURE 4. SYSTEM DAMPING

2.27 3.2.2.1.4 Flight Path Response. The time response of the flight path angle changes in the Landing Flight Phase required by 3.2.3.2.1 shall be smooth. Ninety percent (90%) of the required change in flight path angle at the minimum operational speed shall be obtained in less than 5 seconds, and at the speeds above and below the minimum operational speed, ninety percent of the flight path angle change must be obtained in less than 3 seconds after the pilot command. Following these time periods, the flight path angle shall remain within ± 0.5 degrees about the steady state value. The Figure below illustrates this requirement. This requirement defines Level 1.



Discussion: This requirement was added to ensure that the flight path response to command was rapid and that the flight path change could be maintained. The time of 5 seconds was based on comparison with the B-1 flight path response time during approach, and was also recommended in Reference 5. The time of 3 seconds was suggested in Reference 4. The tolerance band of ± 0.5 degrees about the steady state value was selected arbitrarily.

2.28 3.2.2.2 Control Feel and Stability in Maneuvering Flight. In steady turning flight and in pull-ups at constant speed, the elevator control force and elevator control deflection required to maintain a change in normal acceleration shall be in the same sense as those required to initiate the load factor change; that is, airplane-nose-up control inputs to maintain an increase in normal acceleration, airplane-nose-down control inputs to maintain a decrease in normal acceleration. These requirements apply to local gradients in constant-airspeed maneuvers throughout the range of service load factors defined in 3.1.8.4. This requirement applies for Levels 1 and 2.

Discussion: The major difference between this requirement and the general MIL-F-8785B was that the surface deflection required to maintain commanded normal acceleration was not specified. This was deleted in order to allow flight aft of the maneuver point ($\delta e/g=0$), which may occur at low speeds in the Service Flight Envelope with the flaps down. Augmentation would be required in this region to provide Level 1 flying qualities.

2.29 3.2.2.2.1 Control Forces in Maneuvering Flight. At constant speed in pullups and pushovers, the variations in elevator-control force with steady-state normal acceleration shall be approximately linear. A departure from linearity resulting in a local gradient which differs from the average gradient for the maneuver by more than 50 percent is considered excessive within the Operational and Service Envelopes. All local force gradients shall be within the limits of Table IV. The term gradient does not include that portion of the force versus load factor curve within the preloaded breakout force or friction band. With Normal States that include automatic reduction of pilot control forces for steady state changes in load factor, the gradients of Table IV do not apply.

TABLE IV. Elevator Maneuvering Force Gradient Limits

<u>Center Stick Controllers</u>		
Level	Maximum Gradient, (F_s/n) _{max} pounds per g	Minimum Gradient, (F_s/n) _{min} pounds per g
1	28.0	10.5
2	42.5	9.0
3	56.0	3.0

Wheel Controllers		
Level	Maximum Gradient, (F_s/n) _{max} ' pounds per g	Minimum Gradient, (F_s/n) _{min} ' pounds per g
1	60.0	20.0
2	91.0	19.0
3	240.0	6.0

Discussion: Several changes were made to this requirement from the general MIL-F-8785B (Reference 1). The first was that the requirement applies only for pullups and pushovers and not to steady turning flight. Steady turning flight was deleted since the stick force per "g" gradient (F_s/n) measured in turning flight can differ significantly from that measured in pullups and pushovers as static stability becomes negative (unstable). As static stability decreases to zero, the F_s/n gradients differ by a factor of two for small bank angles. The AMST may be flown at conditions that are statically unstable. Measuring stick forces required to maintain a constant altitude turn would then give misleading values for F_s/n . The general MIL-F-8785B requirement was a pitch sensitivity requirement, and the intent was not to regulate forces required for a turn. The F_s/n measured in a pullup or pushover would indicate the pitch sensitivity of the airplane during maneuvering. Normally, data taken in wind-up turns in flight test would yield F_s/n values approximately the same as for small bank angles.

A change suggested by a contractor but not made was a relaxation of the F_s/n linearity requirement. The contractor felt that linearity was important within the normal load factor range ($n = 1.0g \pm 0.5g$) but that near the limit load factor the maximum pull forces required for maneuvering become the major pilot concern. Frequent maneuvering near the limit load factor would occur with a tactical STOL airplane, and thus other concerns become evident besides the magnitude of the control forces. Consistency of force cues at the same load factors during tactical maneuvering was a concern, as well

as linearity and providing the pilot with sufficient force cues to avoid overstressing the airplane. The entire subject of maneuvering stick forces was very complex and one that would have to be solved by piloted simulation verified by flight test. Until that time when more information would be available, it was decided not to change the present MIL-F-8785B linearity requirement.

Another change was that the requirement did not apply when an automatic system reduced pilot stick forces during maneuvers. With such a system, there would be no steady state F_s/n . Pilots during the AMST flight testing found this type of system to be acceptable, with the possible exceptions of power approach and aerial refueling. The F_s/n requirements should have applied during the transient portion of the maneuver before the automatic system reduced the forces to zero. This would have assured the proper sensitivity for the load factor resulting from force application. This was not done since this AFFTC comment was not available before the AMST Proposal Instruction Package was released. This transient requirement should be incorporated into future revision of the STOL flying qualities requirements.

The actual stick forces in Table IV were based on a limit load factor of 3 except for the wheel, Level 1, minimum gradient which was found to be acceptable from flight test. The AMST has a limit load factor of 3 with the flaps up, and 2 with the flaps down. Based on B-1 and AMST flight testing, the lower gradients were desired by the pilots and were considered acceptable. Flying the AMST aircraft with one hand was stated as a requirement by the Military Airlift Command which the force levels of Table IV made possible. The lower gradients have not resulted in overstressing the aircraft to date. Some pilots were concerned about the ease with which the aircraft could be overstressed, and a "g" limit warning system was suggested.

2.30 3.2.3.2 Longitudinal Control in Maneuvering Flight. Within the Operational Flight Envelope speed range, it shall be possible, except where limited by stall or structural limits, to develop the following range of load factors by use of the primary longitudinal control surface alone:

LEVEL	n_{cmax}	n_{cmin}
1	3.0	0.0
2	2.0	0.25
3	1.25	0.75

This maneuvering capability is required at the 1g trim speed and over a range about the trim speed the lesser of +15 percent or +50 knots equivalent airspeed at constant altitude (except where limited by the boundaries of the Operational Flight Envelope). Trim and throttle settings shall not be changed by the crew. Within the Service and Permissible

Flight Envelopes, the dive-recovery requirements of 3.2.3.5 and 3.2.3.6, respectively, shall be met.

Discussion: The Level 1 load factor capabilities stated above were based on the positive structural limit load factor, and the minimum load factor anticipated to be required to perform the defined missions. The Levels 2 and 3 requirements were based on judgement, although one contractor had performed studies with the SST that indicated the Level 3 values were sufficient for emergency conditions. The speed range over which the maneuver capability shall be demonstrated was defined at constant altitude so that Mach effects were included.

2.31 3.2.3.2.1 Flight Path Angle Change Capability Required for Landing on Tactical Mobility Mission Runway (Paragraph 3.2.1.1 of the System Specification). For the Landing Flight Phase, the required steady state changes in flight path angle ($\Delta\gamma$) about the initially trimmed approach glide slope at constant speed and in calm air are defined as follows:

Speed	$\Delta\gamma$ (deg) - All Engines Operating
V_{min}	Level Flight and -4.0
$V_{\text{min}} + 5\text{Kts}$	-2.0
$V_{\text{min}} - 5\text{Kts}$	+2.0

Sufficient excess thrust shall exist at V_{min} in the landing configuration to land on the runway following loss of thrust of one engine at or below the engine-out go-around decision height (as determined by Combined Test Team) without manually reconfiguring the airplane. This shall be accomplished in a total wind of at least 16 knots as defined by Figure 7/1 with the shears and turbulence defined respectively in 3.7.1 and 3.7.2.2, and with a surface roughness length of 0.15. Maximum crosswind and tailwind components shall be at least 12 knots and 6 knots, respectively, measured at 20 feet. A realistic pilot reaction time shall be used. The landing flap deflection may be established on the basis of airplane weight and wind component. It shall be assumed that the airplane is on the planned approach path to the desired touchdown aim point at the scheduled approach speed when the failure occurs. The touchdown aim point is in the center of the touchdown zone which is defined as the distance the airplane is in the air using the landing performance rules given in Section 50.3 of the System Specification.

For landings made at the field with an engine failed, where the engine failure has occurred above the engine-out go-around decision height, sufficient excess thrust shall exist at V_{min} that the normal approach flight path angles can be maintained. This shall be accomplished in a total wind of at least 23 knots as defined by Figure 7/1 with the shear and turbulence defined respectively in 3.7.1 and 3.7.2.2, and with a surface roughness length of 0.15. Maximum crosswind and tailwind components shall be at least 19 knots and 10 knots, respectively, measured at 20 feet. The landing flap deflection selected for engine-out landing approaches may be established as a function of weight and wind component. To satisfy this requirement, a flight path angle change capability of +2 degrees in calm air is required in addition to that required to maintain normal approach flight path angles in the above stated winds, shears and turbulence. No manually commanded configuration changes are permitted.

The above capabilities must be demonstrated for the weight at the midpoint of the Tactical Mobility Mission defined in the System Specification, 103°F hot day air temperature, and at sea level.

Thrust reductions to stall warning are permitted to demonstrate the required negative changes in flight path angle. For this requirement, all aircraft systems shall be functioning normally, except for the failed engine.

Discussion: This requirement had no counterpart in the general MIL-F-8785B (Reference 1). The requirement was added to specify the minimum flight path control required for STOL operation. The requirement could have a direct impact on sizing the engines since thrust would be the primary means of controlling the flight path on the backside of the power required curve. For this reason, the requirement was discussed more than all the other changes made to the general MIL-F-8785B and was the most controversial. The basis for the requirement was work done by the NASA Ames Research Center and reported in References 4 and 5. Capability to change the flight path was necessary to track to a desired aim point and to correct flight path errors due to the pilot, turbulence or wind shears. Three different cases were addressed in the requirement: All Engines Operating (AEO) and Critical Engine Inoperative (CEI) below and above the engine-out go-around height. The critical case would be the CEI landing where the engine failure occurred above the go-around decision height. Maximum available thrust would be reduced due to the engine failure, and since the probability of this case occurring would be greater than the one where an engine failure occurred below the go-around decision height, higher wind and shear magnitudes must be accounted for in the design. The winds and surface roughness length defined in the requirement were based on ENFTC judgement. No manually commanded configuration changes were allowed once

the landing approach was begun in order to minimize pilot workload. What the configuration change should be would also be difficult to determine since it would be a function of the winds or shears encountered. The configuration change would also take time which may not be available when close to the ground. Manual configuration changes would take longer than automatic since the command must be stated verbally to the copilot who must then respond.

The flight path change of -4 degrees with AEO would result in a total flight path angle of -10 degrees for a -6 degrees STOL approach angle. A capability near this magnitude was required for capturing the STOL glide slope from level flight. Negative corrections to the flight path are not as critical as positive corrections since if the pilot cannot correct downward, a go-around could be commanded and safety not compromised. The pilot must make upward corrections or risk short or high sink rate landings.

For clarification, the touchdown aim point was the center of the touchdown zone which was defined as the distance the airplane was in the air from a 50-foot altitude at the runway threshold to main gear touchdown. This definition for the touchdown zone was used to be consistent with the performance calculation ground rules and since no firm touchdown zone distance was otherwise defined by the procuring activity or MAC. Further, for the CEI landings with the engine failed above the go-around decision height, the requirement was to change the flight path angle +2 degrees about the flight path angle required to land in a 23 knot shearing headwind. A headwind is mentioned here since paragraph 3.7.1 states that the total wind can be from any direction, and a headwind would be the worse case. This 23 knot shearing headwind would have a value of 41 knots at 1,000 feet altitude, which was assumed to be the altitude for the start of final approach. Shearing effects at 1,000 feet would be minimal, but as the altitude decreases, the flight path change capability ($\Delta\gamma$) required to compensate for shearing would increase, while the $\Delta\gamma$ required to compensate for the decreasing headwind would decrease. The $\Delta\gamma$ required for shearing would dominate, and therefore the critical case would be near the ground in a shearing headwind.

2.32 3.2.3.2.1.a Landing in Turbulence. Level 1 flying qualities are required for a landing on the short field defined in paragraph 3.2.1.1 of the System Specification in a total wind of at least 25 knots as defined in 3.7.1, Figure 7/1. The shears and turbulence corresponding to this total wind shall also be considered and are defined in 3.7.1 and 3.7.2.2, respectively, using a surface roughness length of 0.15. For this requirement, maximum crosswind and tailwind components shall be at least 25 knots and 10 knots, respectively, measured at 20 feet.

All airplane systems are assumed to be operating normally.

The weight at the midpoint of the Tactical Mobility Mission defined in the System Specification, 103°F hot day air temperature, and at sea level shall be used for the analysis.

Discussion: Paragraph 3.2.3.2.1.a stated that Level 1 flying qualities were necessary for STOL landings in winds up to those stated, while paragraph 3.2.3.2.1 defined the overall airplane performance required for STOL flight path tracking. Note that a 25 knot crosswind at 20 feet corresponds to a 30 knot crosswind at 50 feet using the turbulence model of Section 3.7. A 30 knot crosswind capability was desired by MAC. The 10 knot tailwind for STOL landing was mentioned by pilots as being the maximum feasible. Tailwind capability was required since in a wartime environment landings may be required in only one direction, or time may not be available to go-around and land from the other direction if winds suddenly change.

2.33 3.2.3.2.2 Turn Rate. During the Landing Flight Phase, at the maximum possible pilot selected flap deflection (contractor may specify specific number), a constant turn rate of 7.5 degrees per second is required for Level 1 at the minimum operational speed and on the trimmed approach glide slope. This condition shall be demonstrated for the weight at the midpoint of the Tactical Mobility Mission defined in the System Specification, 103°F hot day air temperature, all engines operating and at sea level.

Discussion: The intent of this requirement was to provide a sustained turn rate capability for correcting offsets from the runway, avoiding ground fire and other maneuvering tasks. The 7.5 degree/second turn rate was based on the sustained load factor available (i.e., thrust used to maintain load factor) for one of the AMST prototypes at the STOL approach speed. This should provide an acceptable turn rate capability on final based on pilot comments. An 1100 foot turn radius resulted from the 7.5 degree/second turn rate at the STOL approach speeds.

2.34 3.2.3.3 Longitudinal Control in Takeoff. The effectiveness of the elevator control shall not restrict the takeoff performance required of the airplane and defined in the System Specification, and shall be sufficient to prevent over-rotation to undesirable attitudes during takeoffs. Satisfactory takeoffs shall not be dependent upon use of the trimmer control during takeoff or on complicated control manipulation by the pilot. These requirements shall be met on hard-surfaced runways and unprepared fields that are specified in the System Specification. This requirement defines Levels 1, 2, and 3.

Discussion: The requirement in the general MIL-F-8785B (Reference 1) was that the effectiveness of the elevator control could not restrict the takeoff performance, and to obtain nose

wheel liftoff at $0.9 V_{min}$ or less. The $0.9 V_{min}$ requirement was deleted in the AMST wording since meeting that requirement would not assure that the takeoff distance would be achieved. Not restricting takeoff distance was the major intent of the general MIL-F-8785B requirements.

2.35 3.2.3.4 Longitudinal Control in Landing. The elevator control shall be sufficiently effective in the Landing Flight Phase in ground effect that the geometry limited touchdown attitude or the stall angle of attack can be maintained with any thrust setting. This requirement shall be met with the airplane trimmed for the minimum operational speed in free air. The requirements above define Levels 1 and 2. For Level 3, it shall be possible to execute safe approaches and landings in the presence of a 15 kt total mean wind, roughness length of 0.15 and associated turbulence levels as defined in paragraph 3.7.2.2.

Discussion: This requirement was altered to account for the fact that a STOL airplane may not be able to maintain level flight at the geometry limited touchdown attitude. Recognition that the stall angle of attack (or stall speed) was a function of thrust for a STOL airplane was also added. The general MIL-F-8785B (Reference 1) required safe approaches and landings in atmospheric disturbances and the AMST specification quantified these disturbances using engineering judgement. The 15 knot wind of the requirement was intended only as a direct headwind.

2.36 3.2.3.4. Landing Control Power. A load factor (n) of 1.2g's shall be available for flare at the minimum operational speed before the stall warning is encountered. The requirement applies for the Landing Flight Phase, with trim set for approach, without ground effects, and with an initial thrust setting required for the approach configuration and airspeed. This requirement applies for Levels 1, 2, and 3.

Discussion: This requirement was added in the AMST specification to insure that load factor capability was available to flare the airplane from high rates of sink (16 fps) or to make last-second corrections to avoid landing short. This requirement evolved from the criteria presented in Section 5.4.2.1 of Reference 7. The initial concern to provide flare capability was not warranted based on flight test experience for normal operation. Pilots did not intentionally flare the airplane for STOL landing, but tried to hold pitch attitude constant and rely on ground effect to reduce the sink rate. However, some flare capability must be available to arrest higher than normal sink rates due to winds or pilot errors when near the ground.

2.37 3.2.3.4.3 Pitch Acceleration. With the aircraft initially trimmed at the minimum operational speed for the Landing Flight Phase, it shall be possible to achieve a 3-degree attitude

change within one second due to longitudinal column step input only. This requirement defines the minimum Level 1 capability and shall be demonstrated in the most critical steady sideslip required for engine-out or crosswind (3.3.7) and out of ground effects.

Discussion: This requirement was added to the AMST specification based on References 3 and 7. The intent of the requirement was that last-second capability exist to prevent striking the nose gear first on STOL landings. STOL airplanes will generally land at a lower pitch attitude than conventional airplanes. The reason for this is that the angle of attack for STOL and CTOL will be in the region of 7-8 degrees, but the flight path angle for STOL will be near -6 degrees while for CTOL it is near -3 degrees. Thus, STOL pitch attitudes will be approximately 1 to 2 degrees while for CTOL, pitch attitudes are 4 to 5 degrees. Operation in tailwinds could further reduce the STOL pitch attitude to -1 to 0 degrees due to the higher flight path angles required to track to a desired touchdown point. STOL pitch attitude must also be kept low for good pilot visibility on the steep STOL flight path.

2.38 3.2.3.5 Longitudinal Control Forces in Dives - Service Flight Envelope. With the airplane trimmed for level flight at speeds throughout the Service Flight Envelope, the elevator control forces in 7.5 degree dives held for at least 20 seconds duration within the Service Flight Envelope shall not exceed 30 pounds push or 15 pounds pull. In similar dives, but with trim optional following the dive entry, it shall be possible with normal piloting techniques to maintain the forces within the limits of 10 pounds push or pull. The forces required for recovery from these dives shall be in accordance with the gradients specified in 3.2.2.2.1 although speed may vary during the pullout. In no case shall the forces be greater than 100 pounds during the pullout.

Discussion: The major change from the general MIL-F-8785B (Reference 1) was that the dive maneuver was defined based on FAR Part 25, as discussed in 2.7 above. The 100 pounds allowed as the maximum for dive recovery were based on engineering judgement.

2.39 3.2.4 Pitch Attitude Command. For a pitch attitude command mode, the pitch attitude of the aircraft shall be proportional to a longitudinal column displacement from the pitch control trim position. A push force and forward cockpit control displacement shall be required to decrease pitch attitude, and a pull force and aft cockpit control displacement shall be required to increase the pitch attitude. When the column is displaced in either direction and then released, the aircraft shall return to the initially referenced attitude unless the referenced attitude has been changed by a pilot or automatic command. The commanded pitch attitude change versus time shall be smooth, and the required performance defined (i.e., overshoot,

time history envelopes, etc.) by the contractor. The limits on the change in pitch attitude to the pilot stick force shall be defined by the contractor based on prototype flight test results.

Discussion: The intent of this added requirement was to describe in general what an attitude command mode must do, and then let the contractor define the performance characteristics of the mode based on acceptable prototype flight test results. Simulation and analysis could be used to define the characteristics of the mode as long as a comparison with flight test data could be made.

2.40 3.2.5 Airspeed Command and Hold Modes. The command airspeed change versus time shall be smooth and the desired performance defined (i.e., overshoots, time history envelopes, etc.) by the contractor. For an airspeed hold mode, the airspeed selected by the pilot shall be the reference. Indicated airspeed shall be maintained within +5 knots or +2 percent of the referenced airspeed, whichever is greater, excepting gust spikes with a duration less than 2 seconds, in the following atmospheric environment:

Low Altitude - 25 kt total wind using 3.7.1 with a roughness length of 0.15 and a corresponding turbulence as defined in 3.7.2.2.

High Altitude - Use turbulence levels associated with the probability of exceedence of 10^{-2} as defined in Figure 7/6.

Any periodic oscillation within this limit shall have a period of at least 20 seconds.

Discussion: The performance characteristics of a command airspeed mode shall be defined by the contractor, and shall be based on acceptable prototype flight test results. The airspeed hold mode requirements were based on paragraph 3.1.2.7 of Reference 2. Reference 2 requirements were included in the flying qualities specification since at the initiation of the development of these requirements, it was not clear whether the procuring activity was going to specify flight control system (FCS) requirements or not. FCS requirements were eventually written by the procuring activity, but for convenience, the speed hold requirements were left in the flying qualities specification. The atmospheric environments were based on paragraphs 3.1.2.9 and 3.1.3.7.1 of Reference 2, respectively, for the low and high attitudes. Momentary large airspeed excursions due to gust spikes were allowed since no long term degradation in airspeed hold capabilities resulted.

2.41 3.2.6 Pitch Rate Command Mode. For a pitch rate command mode, the pitch rate of the aircraft shall be proportional to

a longitudinal column displacement from the pitch control trim position. A push force and forward cockpit control displacement shall be required for an airplane nose-down pitch rate, and a pull force and aft cockpit control displacement shall be required for an airplane nose-up pitch rate. The commanded pitch rate time history shall be smooth and the required performance defined (i.e., overshoot, time history envelopes, etc.) by the contractor. The limits on the change in pitch rate to the pilot stick force shall be defined by the contractor based on prototype flight test results.

Discussion: Same comments as made under 2.39.

2.42 3.2.7 Pitch Hold Mode. In those airplane states that include attitude hold modes, the airplane shall maintain referenced pitch attitudes throughout the Operational Flight Envelope in the presence of longitudinal trim changes associated with thrust changes, secondary control system operation, normal configuration changes, during lateral-directional maneuvers normally required for mission accomplishment, and in the following atmospheric environment:

Low Altitude - 25 kt total wind using 3.7.1 with a roughness length of 0.15 and a corresponding turbulence as defined in paragraph 3.7.2.2.

High Altitude - Use turbulence levels associated with a probability of exceedence of 10^{-2} as defined in Figure 7/6.

Specifically, attitudes shall be maintained in smooth air with static accuracy of ± 0.5 degree pitch attitude (with wings level) with respect to the reference. RMS attitude deviations shall not exceed 2 degrees in pitch turbulence at the intensities specified. Accuracy requirements shall be achieved and maintained within 3 seconds for either a 5 degree attitude or a 0.5 "g" load factor disturbance, whichever is less, caused by a gust input.

Discussion: This requirement was based initially on paragraph 3.1.2.1 of Reference 2, but evolved further through discussions with the contractors and the Air Force Flight Test Center. Pitch hold mode requirements were included in the flying quality requirements because pitch attitude hold had become an integral part of flying the airplane during STOL landings. The pitch hold mode provides a pseudo speed hold mode since it holds a referenced pitch attitude and the pilot controls the flight path, and hence, angle of attack and air-speed tend to hold a desired value. The atmospheric environment was based on Reference 2 as discussed in 2.40. The 2 degrees RMS attitude deviation (versus the 5 degrees of Reference 2) was suggested by one of the contractors and was

required because of the reliance on attitude hold for airspeed control. The 7 seconds to achieve and maintain the accuracy requirements was selected over the 5 seconds of Reference 2 in order to have a more responsive system to effectively hold airspeed. The 0.5 "g" limit on load factor disturbance was arbitrarily selected as a reasonable upper bound, since the 5 degree pitch attitude disturbance of Reference 2 would result in an excessive load factor disturbance at high dynamic pressure.

2.43 3.3.1 Lateral-Directional Mode Characteristics. The overall lateral-directional damping and frequency requirements for all the system modes (except roll subsidence and structural modes) are shown on Figure 5. The lateral-directional characteristics shall not prevent the pilot from performing accurate touchdowns relative to a 60 foot wide runway.

Discussion: The intent of Figure 5 was to address all characteristic equation roots regardless of the system order, similar to the longitudinal modal characteristics discussed in 2.25. The damping and frequency values of Figure 5 were based on paragraphs 3.3.1.1 and 3.3.1.3 of the general MIL-F-8785B (Reference 1) and Reference 8. The Dutch Roll requirements were also included on the figure showing the minimum Dutch Roll frequencies allowed for Levels 1, 2 and 3. The $\omega^2_{nd} |\phi/\beta|_d$ requirements of the general MIL-F-8785B paragraph 3.3.1.1 were deleted for the AMST since the ϕ/β ratios were small (i.e., normally less than 4). The angular deviation requirement of +3 mils of the general MIL-F-8785B was deleted due to lack of confidence in the requirement.

2.44 3.3.1.2 Roll Mode. The roll-mode time constant, τ_R , shall be no greater than the appropriate value in Table VI.

TABLE VI. Maximum Roll-Mode Time Constant

Flight Phase Category	Level		
	1	2	3
All	1.4	3.0	6.0

Discussion: The roll mode time constants were based on the general MIL-F-8785B (Reference 1), except for the Level 3 value which was influenced by the discussion in Reference 12, page 37. This reference reviews the fact that Level 3 roll mode time constants between 4 and 10 seconds have been suggested or used. The AMST Level 3 roll mode time constant of 6 seconds was

suggested by Reference 8 and did not conflict with Reference 12, therefore, it was used. AMST roll mode time constants were much less than 6 seconds anywhere in the Operational flight envelope.

2.45 3.3.1.3 Spiral Stability. The combined effects of spiral stability, flight control system characteristics, and rolling moment change with speed shall be such that following a disturbance in bank of up to 20 degrees, the time for the bank angle to double will be greater than the values in Table VII, and also shown on Figure 5. This requirement shall be met with the airplane trimmed for wings-level, zero-yaw-rate flight with the cockpit controls free.

TABLE VII. Spiral Stability - Minimum Time to Double Amplitude

Flight Phase Category	Level 1	Level 2	Level 3
ALL	20 sec	12 sec	4 sec

Discussion: This requirement was the same as in the general MIL-F-8785B (Reference 1). A disturbance in bank angle of 10 degrees was used in the V/STOL flying qualities specification (Reference 3), but no difficulties were found using 20 degrees during AMST prototype flight testing.

2.46 3.3.1.4 Coupled Roll-Spiral Oscillation. A coupled roll-spiral mode shall comply with Figure 5.

Discussion: A contractor was concerned about the general MIL-F-8785B (Reference 1) requirement that no coupled roll-spiral modes would be permitted. A coupled roll-spiral mode was possible with the augmentation system on, but it was not noticeable in the response of the airplane. To alleviate the concern of this contractor, the boundaries of Figure 5 were imposed. AFFDL comments concerning Figure 5 boundaries indicated that a coupled roll-spiral mode in the lower right hand corner of Figure 5 may result in very poor flying qualities. However, prototype flight test results did not indicate any potential for a coupled roll-spiral in that region.

2.47 3.3.2.2 Roll Rate Oscillations. Following a rudder pedals free, large step roll control command, the roll rate at the first minimum following the first peak shall be of the same sign and not less than the following percentage of the roll rate at the first peak:

<u>Level</u>	<u>Flight Phase Category</u>	<u>Percent</u>
1	A&B	70
	C	60
2	A&B	60
	C	25
3	ALL	10

For all levels, the change in bank angle shall always be in the direction of the roll control command. The roll command shall be held fixed until the bank angle has changed at least 90 degrees (i.e., -45° to 45°).

Discussion: The roll rate oscillation requirement was made more stringent than the general MIL-F-8785B (Reference 1) based on Reference 13, B-1 data and engineering judgement. Large step roll control commands were specified since Reference 14 stated the requirement was intended for this type of input.

2.48 3.3.2.2.1 Additional Roll Rate Requirement for Small Inputs.

Discussion: This ϕ_{osc}/ϕ_{ay} requirement of the general MIL-F-8785B (Reference 1) was deleted since it was essentially the same as paragraph 3.3.2.3 (ϕ_{osc}/ϕ_{ay}) which was retained. The impulse roll control command of 3.3.2.3 was more suited to flight test, rather than the step roll control input of 3.3.2.2.1 (see page 271, Reference 14).

2.49 3.3.2.4.1 Additional Sideslip Requirements for Small Inputs.

Discussion: This requirement from the general MIL-F-8785B (Reference 1) was deleted due to lack of confidence in the requirement, as well as difficulty in reducing flight test data to show compliance with the requirement. B-1 experience indicated that the requirement could be met in the landing configuration, but that exceptionally poor turn coordination was still evident (B-1 characteristics were improved with the addition of adverse yaw compensation).

2.50 3.3.2.5.1 Lateral Acceleration Limits, Rolling. For Level 1, the body axis lateral acceleration at the center of gravity shall not exceed a limit defined by a linear variation between $+0.1g$ at zero roll rate and $+0.55g$ at 60 deg/sec, and $+0.55g$ for roll rates greater than 60 deg/sec. These limits shall be satisfied for aircraft in essentially constant altitude flight while rolling smoothly from one side to the other with rudder pedals used for coordination.

Discussion: This requirement was initially added from Reference 2, paragraph 3.1.2.4.2, as a method of insuring good

turn coordination. It was added since it was questionable if there was going to be a procuring activity Flight Control System specification as mentioned in 2.40. The actual accelerations allowed at the center of gravity were based on AMST prototype flight test, and were found to be acceptable. The validity of this requirement is questionable since for a pilot coordinated turn, the accelerations should be related to the pilot station and not the center of gravity.

2.51 3.3.2.6 Turn Coordination. For Level 1, the sideslip angle shall not be greater than two degrees and lateral acceleration shall not exceed 0.03g during steady coordinated turns in either direction using 45 degrees of bank. Rudder pedal force shall not exceed 40 pounds. It shall be possible to perform steady turns at the same bank angles with rudder pedals free, with a roll stick force not exceeding five pounds or a roll wheel force not exceeding 10 pounds. The force requirements constitute Levels 1 and 2 with the airplane trimmed for wings-level constant flight path and heading angle flight.

Discussion: The general MIL-F-8785B (Reference 1) requirement was modified with the intention of making it more specific using paragraph 3.1.2.4.1 of Reference 2 as a guide. The Class II requirement of 45 degrees of bank angle in the general MIL-F-8785B was used since a high maneuver capability was required for the AMST.

2.52 3.3.2.7 Residual Oscillations. Any sustained residual oscillations shall not interfere with the pilot's ability to perform the tasks required in the service use of the airplane. For Level 1, oscillations in lateral acceleration at the pilot's station greater than +0.01g will be considered excessive for any Flight Phase.

Discussion: A lateral oscillation requirement was added to be consistent with the longitudinal residual oscillations of paragraph 3.2.2.1.3. This requirement was based on paragraph 3.1.3.8 of Reference 2. Roll and yaw attitude oscillations were not specified due to lack of confidence in the Reference 2 numbers.

2.53 3.3.4 Roll Control Effectiveness. Roll performance in terms of bank angle change in a given time, ϕ_t , is specified in Table VIII. Roll control commands shall be initiated from zero roll rate in the form of abrupt inputs, with time measured from the initiation of control force application. Rudder pedals may be used to reduce sideslip that retards roll rate (not to produce sideslip that augments roll rate) if rudder pedal inputs are simple, easily coordinated with roll control inputs, and consistent with piloting techniques. Roll control with all systems operating normally shall be sufficiently effective to balance the airplane in roll throughout the Service Flight

Envelope in turbulence levels associated with a probability of exceedence of 10^{-5} as defined in Figure 7/6. The Category C, Level 3 roll requirement shall be met with a maximum crosswind magnitude as specified in 3.3.7.

TABLE VIII. Maximum Time to Achieve 30° Bank Angle*

Flight Phase Category	Time (sec)		
	Level 1	Level 2	Level 3
A & B**	2.0	3.0	4.0
C	2.5	3.2	4.0

*For takeoff, the required bank angle can be reduced proportional to the ratio of the maximum rolling moment of inertia for the maximum authorized landing weight to the rolling moment of inertia at takeoff, but the Level 1 requirement shall not be reduced below the listed value for Level 3.

**For Aerial Delivery at $1.2 V_S$, Category C requirements apply.

Discussion: The times to achieve 30 degrees of bank angle for Level 1 were based on AMST prototype flight test data. The Levels 2 and 3 times were based on the numbers in the general MIL-F-8785B (Reference 1) for a Class III airplane. The AMST roll capability was evaluated and found to be acceptable during: STOL operation with an engine failed; MAC tactical maneuvers; in turbulence and crosswinds; and in formation flight. The critical point in the flight envelope to meet the roll requirements for the AMST was at low altitude and low speed. The roll requirements must be met at the minimum operational speed of $1.4V_S$ flaps up, aerial delivery excluded, and $1.2V_S$ flaps down based on paragraph 3.1.7.2. The general MIL-F-8785B required that the roll control balance the airplane in atmospheric disturbances. The worst disturbances defined were thunderstorm root mean square velocities (σ_u , σ_v and σ_w) of 21 feet per second. The new turbulence model used in the AMST specification indicated that the 21 feet per second velocities were approximately defined by a probability of exceedence of 1×10^{-5} (see Figure 7/6). This probability of exceedence was used in the AMST requirement. Finally, there was a concern that large sideslip angles during a wing-down approach in large crosswinds would require significant amounts of lateral trim, which then would affect the roll capability. For this reason, the last sentence was added to prevent the roll capability from degrading to an unsafe level in crosswind. This concern does not appear to be justified based on AMST flight test results.

2.54 3.3.4.3 Linearity of Roll Response. There shall be no objectionable nonlinearities in the variation of roll rate for a rate command system and of roll attitude for an attitude command system with roll control deflection or force. This is considered a Level 1 and 2 requirement.

Discussion: The "rolling response" linearity required by the general MIL-F-8785B (Reference 1) has been redefined as shown above in order to be more specific. The sensitivity or sluggishness requirement of the general MIL-F-8785B was deleted since it was not specific. A sensitivity requirement based on Reference 12 and shown below was included in the early drafts of the AMST specification. It was eventually deleted, but the rationale for this was not recorded. It may have been deleted since the roll response due to pilot force was required to be defined based on prototype flight test in paragraphs 3.3.10 and 3.3.11.

Roll Control Sensitivity. The roll control sensitivity will be stated as the ratio of the change in bank angle in one second to inches of roll control deflection (i.e., $\Delta\phi_1/\Delta\delta w$). For a wheel, the inches of deflection are measured along the circumference distance that the index finger of the pilot moves when the wheel is turned. The sensitivities are shown below and are intended to apply for small roll control commands.

LEVEL	$\Delta\phi_1/\Delta\delta w$ (deg/in)
1	0.72 to 1.8
2	.36 to .72 and 1.8 to 2.5

2.55 3.3.4.5 Rudder-Pedal Induced Rolls. Deleted.

Discussion: The requirement of the general MIL-F-8785B (Reference 1) was deleted from the AMST specification since a roll attitude hold mode was a basic mode of the flight control system. This mode prevented the airplane from rolling due to rudder pedal inputs. A special modification of the roll attitude hold mode would have been required to meet this requirement, but AMST flight test results indicated that this was not necessary. The basic roll attitude hold characteristics were acceptable.

2.56 3.3.5.3 Yaw Control. Within the Operational Flight Envelope for the Landing Flight Phase, the yaw attitude changes in 2 seconds for an abrupt step displacement of the yaw control shall be between 5 and 10 degrees for Level 1. This requirement applies with the aircraft trimmed for symmetrical flight and with the wings held level during the maneuver.

Discussion: This requirement was added to the AMST

specification to insure adequate yaw control to decrab the airplane during landings in crosswinds of up to 30 knots. The requirement was initially based on work reported in Reference 7, but the final numbers were based on acceptable AMST flight test results and contractor comments.

2.57 3.3.5.4 Yaw Control Linearity and Sensitivity. There shall be no objectionable nonlinearities in the variation of directional response with yaw control deflection or forces. There shall be no excessive sensitivity or sluggishness of airplane yaw response due to rudder pedal deflection or force that would prevent such things as satisfactory turn coordination, decrab for touchdown in crosswind, or control of engine failure transients.

Discussion: This requirement was initially intended to address more specifically the yaw control linearity and sensitivity than paragraph 3.3.5 of the general specification (Reference 1). Initial drafts of the AMST specification had a Level 1 sensitivity requirement of 0.05 to 0.10 rad/sec² due to a 1.0 inch rudder pedal input. This sensitivity was based on Reference 15. AMST flight test results indicated that for one airplane, the yaw acceleration was lower than 0.05 rad/sec, yet the yaw response was generally considered acceptable by the pilots. A qualitative sensitivity requirement as shown above was eventually added since a good quantitative requirement could not be verified.

2.58 3.3.5.5 Heading Control. Within the Operational Flight Envelope for Category C, the heading delay τ_ψ , shall be less than the values shown below:

LEVEL	τ_ψ , sec
1	1.2
2	2.0
3	3.0

The aircraft shall be initially trimmed when the maneuver is begun. An explanation of τ_ψ is presented in 6.2.6.

Discussion: This requirement was added to ensure good transient turn coordination characteristics for the various Levels. The requirement was based on Reference 12, which did not provide much supporting data. The parameter τ_ψ is the heading response time delay for a commanded step bank angle change (see the Appendix, paragraph 6.2.6). This paragraph was added to provide a quantitative assessment of turn coordination since the general MIL-F-8785B (Reference 1) requirement 3.3.2.4.1 was deleted for the reasons given in 2.49 above.

2.59 3.3.6 Lateral-Directional Characteristics in Steady

Sideslips. The requirements of 3.3.6.1 through 3.3.6.3.1 concern rudder pedal induced, unaccelerated, zero yaw rate sideslips with the airplane trimmed for wings level, constant flight path and heading angle. Paragraphs 3.3.6.1 through 3.3.6.3 apply at sideslip angles up to those produced by full rudder pedal deflections.

Discussion: The general MIL-F-8785B (Reference 1) requirement was modified to consider all sideslip angles produced by full rudder pedal deflections. The general MIL-F-8785B allowed sideslip angles to be limited by 250 pounds of rudder pedal force or maximum roll control. These limitations were not considered necessary for the AMST.

2.60 3.3.6.3 Rolling Moments in Steady Sideslips. For the sideslips of 3.3.6, left or zero roll control deflection and force shall accompany left sideslips, and right or zero roll control deflection and force shall accompany right sideslips. For Levels 1 and 2, the variation of roll control deflection and force with sideslip angle shall be linear.

Discussion: The AMST utilized a roll attitude hold mode, and thus, zero roll control deflection and force were required to hold a steady sideslip. Pilots considered these characteristics acceptable and desirable.

2.61 3.3.7 Lateral Directional Control in Crosswinds. It shall be possible to take off and land with normal pilot skill and technique in crosswinds 90 degrees to the runway with velocities up to those specified in Table X. Level of flying quality in zero crosswind shall be maintained for crosswinds up to the magnitudes shown in Table X, although the pilot workload may increase. Roll control forces shall not exceed 10 pounds for Level 1 or 20 pounds for Levels 2 and 3. Rudder pedal forces shall not exceed 100 pounds for Level 1, 140 pounds for Level 2, and 180 pounds for Level 3.

TABLE X. Crosswind Velocity

Level	Crosswind at 50 ft Altitude
1 & 2	30 Knots
3	15 Knots

Discussion: Three major changes have been made to this requirement from the general MIL-F-8785B (Reference 1). The first was that the flying qualities evident in calm air (e.g., Level 1) must not degrade during a crosswind landing. Based on

prototype flight test results, this was a realistic requirement. The second item was that the crosswind magnitude was quoted at 50 feet. This was important since winds vary as a function of altitude due to shears, as defined in the Appendix, paragraph 3.7.1. Finally, the roll and rudder control forces were based on AMST characteristics. Note that a crosswind of 30 knots at STOL approach speeds results in a sideslip angle near 20 degrees which may be the critical design case for rudder sizing and selection of the vertical tail airfoil to avoid fin stall.

2.62 3.3.7.1 Final Approach in Crosswinds. Deleted.

Discussion: This requirement was deleted since 3.3.7 defined that the airplane must be capable of landing in crosswinds. The contractor should be allowed to determine what rudder, aileron or landing gear capability is required to achieve the required crosswind landings.

2.63 3.3.9.1 Thrust Loss During Takeoff Run. It shall be possible for the pilot to maintain control of an airplane on the takeoff surface following sudden loss of thrust from the most critical factor. Thereafter, it shall be possible to achieve and maintain a straight path on a concrete (hard) takeoff surface without a deviation of more than 30 feet from the path originally intended, with rudder pedal forces not exceeding 120 pounds. For the Tactical Mobility Mission runway defined in paragraph 3.2.1.1 of the System Specification, deviation from the path originally intended shall not result in the main landing gear tires extending beyond the runway edge, nor the rudder pedal forces to exceed 120 pounds. The deviations from the intended path shall be analyzed for a sudden fuel cut-off to the critical engine, with a 1 second time delay between the time of the engine failure and the start of the pilot control input. Flight test results shall be used to demonstrate that the deviations from the path intended are less than required above. The deviations measured from flight test shall include a pilot delay time determined by adding the largest flight test delay time plus an additional 0.2 seconds to account for normal pilot surprise. For the continued takeoff, the allowable deviations shall not be exceeded when thrust is lost from the refusal speed (based on the shortest runway defined in the System Specification) to the maximum takeoff speed, with takeoff thrust maintained on the operative engine(s), using only pitch, roll and yaw controls. No forward movement or pressure shall be applied to the control column. For the aborted takeoff, the allowable deviations shall not be exceeded at all speeds below the maximum takeoff speed. However, additional controls such as nosewheel steering and differential braking may be used. Automatic devices which normally operate in the event of a thrust failure may be used in either case.

Discussion: Several changes were made to this requirement from the general MIL-F-8785B (Reference 1). The first was that the requirement addressed the 60 feet wide Tactical Mobility Mission runway since the conventional 30 feet lateral deviation would result in landing gear tires off the runway. Any future release of the Proposal Instruction Package would further clarify that none of the main landing gear tires could extend beyond the edge of the runway. Secondly, the critical test condition of a sudden fuel cut-off to the engine was defined in order to simulate an engine failure due to rotor seizure or burst. Even though the sudden fuel cut-off would be used for analysis and test verification of this requirement, it was still intended that all critical engine failure cases be analyzed. The wording of the Reference 1 requirement was perhaps misleading as to which cases were to be analyzed, and this should be corrected in any future revision of the requirement. Third, the 1 second pilot delay time was not considered reasonable by a contractor due to experience with FAA certification of commercial airplanes. Since no firm historical basis could be determined, the measured pilot delay time was allowed to show compliance with the requirement. A 0.2 seconds additional time was defined to account for surprise, and was based on discussions with USAF Aeromedical Laboratory personnel. Finally, nose wheel steering was allowed for the continued take-off if the inputs were made through the rudder pedals. No forward movement or pressure on the control column was permitted to prevent an improvement of nose wheel steering characteristics by increasing the normal force on the nose wheel. This was prohibited since on the soft Tactical Mobility Field, unacceptable rutting might be caused by this procedure.

2.64 3.3.9.2 Thrust Loss After Takeoff. For takeoff, it shall be possible without a manually commanded configuration change to achieve constant flight path and heading angle following sudden asymmetric loss of thrust at Service Flight Envelope speeds from V_{min} (TO) to V_{max} (TO). Thereafter, it shall be possible to maintain constant flight path and heading angle throughout the climbout. The rudder pedal force shall not exceed 120 pounds. Roll control force shall not exceed the Level 3 force limits specified in 3.3.4.2. The Category C, Level 3, roll requirement of 3.3.4 shall be met with takeoff thrust maintained on the operative engine(s) and trim at normal settings for takeoff with symmetric thrust. Automatic devices which normally operate in the event of a thrust failure may be used, and the airplane may be banked up to 5 degrees in the direction to assist control.

Discussion: This requirement was basically the same as the general MIL-F-8785B (Reference 1). Automatic configuration changes during takeoff were allowed since the pilot would not have to monitor the change. The MIL-F-8785B 75% limit on lateral control for trimming an engine failure was revised to require that the AMST be capable of at least Category C, Level 3 roll performance. This change was made since the 25% margin on lateral control was to provide

roll capability, and the AMST requirement defines specifically what capability was required. The AMST may also be banked up to 5 degrees in any direction to assist control in order to relieve lateral or directional control requirements.

2.65 3.3.10 Roll Attitude Command. For a roll attitude command mode, the roll attitude of the aircraft shall be proportional to a fixed roll control displacement from the roll control trim position. Right roll control displacement and force shall cause a positive increase in bank angle, and a left control displacement and force shall cause a decrease in positive bank angle. When the roll control is displaced in either direction and then released, the aircraft shall return to the initially referenced roll attitude. The command roll attitude change versus time shall be smooth, and the desired performance (i.e., overshoot, time history envelopes, etc.) defined by the contractor. The limits on the change in roll attitude to the pilot's roll control force shall be defined by the contractor based on prototype flight test results.

3.3.11 Roll Rate Command Mode. For a roll rate command mode, the roll rate of the airplane shall be proportional to a fixed roll control displacement from the roll control trim position. Right roll control displacement and force shall cause a right wing down roll rate, and a left roll control displacement and force shall cause a left wing down roll rate. The commanded roll rate time history shall be smooth, and the desired performance (i.e., overshoot, time history envelopes, etc.) defined by the contractor. The limits on the commanded roll rate to the pilot roll control force shall be defined by the contractor based on prototype flight test results.

3.3.12 Roll Attitude Hold Mode. For a roll attitude hold mode, the referenced roll attitude shall be maintained in smooth air with a static accuracy of ± 1.0 degree. RMS attitude deviations shall not exceed 10 degrees in roll attitude in the following atmospheric environment:

Low Altitude - 25 kt total wind using 3.7.1 with a roughness length of 0.15 and corresponding turbulence as defined in paragraph 3.7.2.2.

High Altitude - Use turbulence levels associated with a probability of exceedence of 10^{-2} as defined in Figure 7/6.

Accuracy requirements shall be achieved and maintained within 3 seconds for a 5 degree attitude disturbance due to gust.

Discussion: The discussion of 2.39 applies to the above paragraphs 3.3.10 and 3.3.11. The discussion for 2.40 explains where the turbulence magnitudes of paragraph 3.3.12 originated. The roll attitude requirement was based on paragraph 3.1.2.1

of Reference 2.

2.66 3.4.1 Dangerous Flight Conditions. Dangerous conditions may exist where the airplane should not be flown. When approaching these flight conditions, it shall be possible by clearly discernible means for the pilot to recognize the impending dangers and take preventive action.

Discussion: Procuring activity approval of warning indications and devices to prevent entry into dangerous conditions was deleted from the general MIL-F-8785B (Reference 1) requirement. A procuring activity management directive was to delete such references. The reason for this was that if the procuring activity approved a warning or preventative device and then the system did not perform satisfactorily in flight, the contractor might not be contractually responsible for correcting the system. The preliminary activity approval would have indicated that the system satisfied the contractual requirements. The contractor is solely responsible for providing adequate warning as the pilot approaches dangerous conditions. These same comments apply to paragraph 3.4.1.2:

2.67 3.4.2.1 Stalls. Stall usually is a phenomenon caused by airflow separation induced by high angle of attack, and for the C-1XA, a reduction in thrust; it may also be defined by some limit on usable angle of attack (3.1.9.2). The stall requirements apply for all Airplane Normal States in straight unaccelerated flight and in turns and pull-ups with attainable normal acceleration up to n_L . The pilot shall be warned when Failure States (other than Special Failure States) exist that affect stall characteristics. The pilot shall be able to safely terminate or complete the flight phase that was in progress at the time of the failure.

Discussion: References to paragraphs 6.2.2 and 6.2.5 in the general MIL-F-8785B (Reference 1) were deleted since the stall speed definition was moved into Section 3 of the AMST specification, paragraph 3.1.9.2. Stall speed was defined in the main body of the specification for added emphasis. The AMST requirement also recognized that for a STOL airplane, stall is a function of thrust setting. The last phrase of the general MIL-F-8785B paragraph was deleted since it was argued that it was too general and unrealistic to require that all stall requirements be met with any failure state that affects stall characteristics. For example, during unaccelerated stalls with asymmetric flaps or slats the airplane would not have been allowed to roll off more than 20 degrees.

2.68 3.4.2.1.1 Stall Approach. The stall approach shall be accompanied by an easily perceptible warning. Acceptable

stall warning for all unaccelerated and accelerated stalls consists of shaking of the cockpit controls, buffeting or shaking of the airplane, or a combination of both. The onset of this warning shall occur within the ranges specified in 3.4.2.1.1.1, but not within the Operational Flight Envelope. The warning shall continue until the angle of attack is reduced to a value less than that for warning onset. At all angles of attack up to the stall, the cockpit controls shall remain effective in their normal sense, and small control inputs shall not result in departure from a controlled flight. Prior to the stall, uncommanded oscillations shall not be objectionable to the pilot.

3.4.2.1.1.1 Warning Speed for Stalls at lg Normal to the Flight Path. Warning onset for stalls (3.1.9.2) at lg normal to the flight path, shall occur between the following limits when the stall is approached gradually:

<u>Flight Phase</u>	<u>Minimum Speed for Onset</u>	<u>Maximum Speed for Onset</u>
Approach	Higher of $1.05V_S$ or $V_S + 5$ knots	Higher of $1.10V_S$ or $V_S + 10$ knots
All Other	Higher of $1.05V_S$ or $V_S + 5$ knots	Higher of $1.15V_S$ or $V_S + 15$ knots

3.4.2.1.1.2 Warning Range for Accelerated Stalls. Deleted.

Discussion: Paragraphs 3.4.2.1.1, 3.4.2.1.1.1 and 3.4.2.1.1.2 of the general MIL-F-8785B (Reference 1) were modified as shown above. Both unaccelerated and accelerated stalls were addressed in 3.4.2.1.1 since the same warning and control characteristics were desired for both types of stalls. The warning range for accelerated stalls (3.4.2.1.1.2) was deleted since little difference was seen in the lift coefficient margin provided by 3.4.2.1.1.1 or 3.4.2.1.1.2.

2.69 3.4.2.1.2 Stall Characteristics. In the unaccelerated stalls of 3.4.2.1 the airplane shall not exhibit rolling, yawing, or pitching at the stall which cannot be controlled to stay within 20 degrees. It is desired that no pitch-up tendencies occur in unaccelerated or accelerated stalls. In unaccelerated stalls, mild nose-up pitch motion may be acceptable if no dangerous, unrecoverable, or objectionable flight conditions result. A mild nose-up tendency may be acceptable in accelerated stalls if the operational effectiveness of the airplane is not compromised and:

- a. The airplane has adequate stall warning.
- b. Pitch surface effectiveness is such that it is possible to stop the pitch-up motion promptly and reduce the angle of attack, and

c. At no point during the stall, stall approach, or recovery does any portion of the airplane exceed structural limit loads.

These requirements apply for all stalls, including stalls entered abruptly.

Discussion: The pitching motion discussed in the first sentence of this paragraph should have been clarified as only in a downward direction, as was done in the general MIL-F-8785B (Reference 1). The general MIL-F-8785B requirement also did not allow elevator control force reversal, but it was allowed in the AMST specification.

2.70 3.4.2.1.3 Stall Prevention and Recovery. It shall be possible to prevent the stall by moderate use of the pitch or throttle control at the onset of the stall warning. It shall be possible to recover from a stall by simple use of the pitch, roll, and yaw controls with cockpit control forces not to exceed those of 3.4.5.1, and to regain level flight without excessive loss of altitude or buildup of speed. Throttles may be changed to aid stall recovery. In the straight flight stalls of 3.4.2.1, with the airplane trimmed at an airspeed not greater than $1.4 V_S$, and with a speed reduction rate of at least 4.0 knots per second, the pitch control power shall be sufficient to recover from any attainable angle of attack.

Discussion: The above requirement allows throttles to be used to prevent stall or for stall recovery, since with a STOL airplane this may be the most effective method. A speed reduction rate of 4.0 knots per second was defined in order to be specific even though this was not defined in the general MIL-F-8785B (Reference 1). This rate was taken from the original issue of the flying qualities specification, MIL-F-8785B, dated 7 August 1969.

2.71 3.4.2.2.2 Recovery From Post-Stall Gyration and Spins. The airplane must be readily recoverable from all attainable attitudes and motions. The post-stall characteristics shall be determined.

Discussion: The general MIL-F-8785B (Reference 1) required that the post-stall characteristics be determined by analysis and model tests. The methods of determining the post-stall characteristics were not defined in order not to specify the techniques used to design an airplane. The specification defines only what performance is required.

2.72 3.5 Characteristics of the Manual Flight Control

System (MFCS).

3.5.1 General Characteristics. Manual Flight Control Systems consist of electrical, mechanical and hydraulic components which transmit pilot control commands or generate and convey commands which augment pilot control commands, and thereby accomplish flight control functions. This classification includes the longitudinal, lateral-directional, lift and drag control systems. In addition, their associated augmentation, performance limiting and control devices are included. Thrust control shall also be included in this definition if thrust is used by the pilot to control the flight path of the aircraft. The requirements of this section are concerned with those aspects of the Manual Flight Control System which are directly related to flying qualities.

Discussion: The terminology of the Flight Control System specification, MIL-F-9490D (Reference 2), was used in the AMST flying qualities specification for uniformity. Paragraph 1.2.1.1 of MIL-F-9490D was the basis for the above definition of the Manual Control System.

2.73 3.5.2.1 Control Centering and Breakout Forces. Longitudinal, lateral, and directional controls should exhibit positive centering in-flight at any normal trim setting. Although absolute centering is not required, the combined effects of centering, breakout force, stability and force gradient shall not produce objectionable flight characteristics, such as poor precision tracking ability, or permit large departures from trim conditions with controls free. Breakout forces, including friction, preload, etc., shall be within the limits of Table XI. The values in Table XI refer to the cockpit control force required to start movement of the control surface in flight.

TABLE XI. Allowable Breakout Forces, Pounds

LEVEL	MINIMUM-MAXIMUM BREAKOUT FORCE - LB		
	Pitch Column	Rudder Pedals	Wheel
1	1.0 to 5.0	5.0 to 8.0	0.5 to 4.0
2	0.5 to 7.0	2.0 to 14.0	0.5 to 7.0
3	0 to 10.0	0 to 28.0	0 to 10.0

Measurement of breakout force on the ground will ordinarily suffice in lieu of actual flight measurement, provided that qualitative agreement between ground measurement and flight observation can be established.

Discussion: The general specification (Reference 1) did

not degrade forces for Level 2, but this was desired. The breakout forces in Table XI were suggested by one of the AMST contractors and since they appeared to be reasonable they were used.

2.74 3.5.2.3 Rate of Control Displacement. The ability of the airplane to perform the operational maneuvers required of it shall not be limited in the atmospheric environment specified in 3.7 by control surface deflection rates. Adequate control of the airplane shall be maintained in the following environment:

Low Altitude - 25 kt total wind using 3.7.1 with a roughness length of 0.15 and corresponding turbulence as defined in paragraph 3.7.2.2.

High Altitude - Use turbulence levels associated with a probability of exceedence of 10^{-5} as defined in Figure 7/6.

The effect of engine speed and the duty cycle of the Manual Flight Control System together with the pilot control techniques shall be included when establishing compliance with this requirement.

Discussion: The general MIL-F-8785B (Reference 1) defined specific atmospheric disturbances in which the ability to perform operational maneuvers should not be limited by surface deflection rates. The above environment was selected as explained in 2.40 and 2.53 to be comparable, for the worst case, with that defined in the general MIL-F-8785B. The total wind and probability of exceedence are related to the new atmospheric model of the AMST specification. By "adequate control" in the above requirement, it was meant that the pilot does not lose control of the airplane.

2.75 3.5.3 Dynamic Characteristics. The response of the control surfaces in flight shall not lag the cockpit control force inputs by more than the angles shown in Table XII for frequencies equal to or less than the frequencies shown in Table XII.

TABLE XII. Allowable Control Surface Lags

Level	Allowable Lag ~ deg		Control	Upper Frequency ~ rad/sec
	Category A and C Flight Phases	Category B Flight Phases		
1 and 2	30	45	Pitch	ω_{NSP} or 2 (whichever is larger)
3	60		Rudder & Roll	ω_{nd} or $\frac{1}{\tau_R}$ (whichever is larger)

Discussion: The upper frequency for pitch was further defined as two radians/second based on discussions with NASA Ames Research Center personnel. This was done since the STOL airplane may have very low short period natural frequencies. However, the flight control system should still have good response characteristics up to at least two radians/second.

2.76 3.5.3.2 Damping. All control system oscillations shall be well damped (see paragraph 3.2.2.1.2) unless they are of such an amplitude, frequency, and phasing that they do not result in objectionable oscillations of the cockpit controls or the airframe during abrupt maneuvers and during flight in atmospheric environments up to the following:

Low Altitude - 25 kt total wind using 3.7.1 with a roughness length of 0.15 and corresponding turbulence as defined in paragraph 3.7.2.2.

High Altitude - Use turbulence levels associated with a probability of exceedence of 10^{-5} as defined in Figure 7/6.

Discussion: See discussion of 2.74.

2.77 3.5.4.1 Performance of Augmentation Systems. Performance degradation of augmentation systems caused by atmospheric disturbances and by structural vibrations shall be considered.

Discussion: The general MIL-F-8785B (Reference 1) defines specific atmospheric environments in which to consider performance degradations of the augmentation. The above requirement deleted specific reference to atmospheric environments since they had been addressed in the flight control system performance requirements of 3.5.2.3, 3.5.3.2 and 3.5.4.2. This requirement could have been deleted since it added nothing to what had been required by 3.5.2.3, 3.5.3.2 and 3.5.4.2.

2.78 3.5.4.2 Saturation of Augmentation Systems. Limits on the authority of augmentation systems or saturation of equipment shall not result in objectionable flying qualities. In particular, this requirement shall be met during rapid large amplitude maneuvers, during operation near V_g , and during flight in the atmospheric environment of paragraph 3.7. Saturation shall not degrade control below an adequate level for the following atmospheric environment:

Low Altitude - 25 kt total wind using 3.7.1 with a roughness length of 0.15 and corresponding turbulence as defined in paragraph 3.7.2.2.

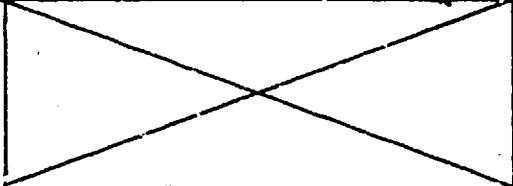
High Altitude - Use turbulence levels associated with a probability of exceedence of 10^{-5} as defined in Figure 7/6.

Discussion: See discussion of 2.74.

2.79 3.5.5 Failures. If the flying qualities with any or all of the augmentation devices inoperative or partially inoperative are dangerous or intolerable, provisions shall be incorporated to preclude the occurrence of that set of failures within the probability of encountering less than Level 3 flying qualities established in paragraph 3.1.10.2. Failure induced transient motions and trim changes resulting either immediately after failure or upon subsequent transfer to alternate control modes shall be small and gradual enough that dangerous flying qualities are extremely remote.

Discussion: The argument was made that the general MIL-F-8785B (Reference 1) requirement did not allow for a "critical single failure" being a special failure state, and that large and sudden transients due to failures should "never result" was unreasonable. The above wording changes were made to resolve those concerns.

2.80 3.5.5.1 Failure Transients. With controls free, the airplane motions due to failures described in 3.5.5 shall not exceed the following limits for at least 2 seconds following the failure as a function of the Level of flying qualities after the failure transient has subsided:

Level (after failure)	Normal or Lateral Acceleration at Pilot's Station		Roll Rate	
	Categories A&B	Category C	Categories A&B	Category C
1	$\pm 0.5g$	$\pm 0.2g$	± 10 deg/sec	± 4 deg/sec
2	$\pm 0.5g$	$\pm 0.4g$	± 10 deg/sec	± 8 deg/sec
3	Transients due to failures shall not exceed 75 percent of limit normal or lateral load factor.			

Discussion: There was some concern that the general MIL-F-8785B (Reference 1) requirement of $\pm 0.05g$ normal or lateral acceleration transient for Level 1 after the failure was too stringent. The above requirement was incorporated since

Reference 14 suggested a relaxation in the requirement if the cost and complexity of the flight control system could not be justified, and since it was compatible with paragraph 3.1.3.3.4 of the Flight Control System specification (Reference 2). Reference 2 was also the basis for the Levels 2 and 3, Categories A and B requirements. The AMST specification addressed Category C separately since the failure transient values suggested in references 1 and 2 were considered excessive for Category C. The values stated for Category C were arrived at mutually by the procuring activity and an AMST contractor based on engineering judgement.

2.81 3.5.6.1 Transients. With controls free, the transients resulting from the situations described in 3.5.6 shall not exceed the following limits for at least 2 seconds following the transfer:

Within the Operational Flight Envelope	+0.05g normal or lateral acceleration at the pilot's station and +1 degree per second roll.
Within the Service Flight Envelope	+0.5g normal or lateral acceleration at the pilot's station or +5 degrees per second roll.

These requirements apply only for Airplane Normal states.

Discussion: The requirement within the Service Flight Envelope was modified to address normal and lateral accelerations. The service flight envelope sideslip and structural limits of the general MIL-F-8785B (Reference 1) were addressed by the lateral acceleration limit.

2.82 3.6.3.1 Pitch Trim Changes. The pitch trim changes caused by operation of the Manual Flight Control System shall not be so large that a peak pitch control force in excess of 20 pounds is required under conditions representative of operational procedures. Generally, the conditions listed in Table XIII will suffice for determination of compliance with this requirement. With the airplane trimmed for each specific initial condition, the peak force required to maintain the specified parameter constant following the specified configuration change shall not exceed 20 pounds for at least 5 seconds following the completion of the pilot action initiating the configuration change. The magnitude and rate of trim change subsequent to this time period shall be such that the forces are easily trimmed by use of the normal trimming devices. The above requirements define Level 1. For Levels 2 and 3, the allowable forces are increased by 50 percent. If automatic trim devices are selectable by the pilot, they shall be inoperable when showing compliance with this requirement.

Table XIII. Pitch Trim Change Conditions

	Flight Phase	Initial Trim Conditions					Configuration Change	Parameter to be held constant
		Altitude	Speed	Landing Gear	High-lift Devices	Thrust		
1	Approach	h_{0min}	Normal pattern entry speed	Up	Up	TLF	Gear down	Altitude and airspeed *
2				Up	Up	TLF	Gear down	Altitude
3**				Down	Up	TLF or normal thrust	Extend high lift devices to approach deflection	Normal altitude and airspeed *
4**				Down	Up	TLF or normal thrust	Extend high lift devices to approach deflection	Normal altitude
5				Down	Approach deflection	TLF	Minimum thrust	Airspeed
6***			V_{0min}	Down		TLF or normal thrust	Extend Deceleration Device	Airspeed

TABLE XIII. Pitch Trim Change Conditions (cont)

	Flight Phase	Initial Trim Conditions					Configuration Change	Parameter to be held constant
		Altitude	Speed	Landing Gear	High-lift Devices	Thrust		
7**	↓			Down		TLP or normal thrust	Takeoff thrust	Airspeed
8**	Approach			Down	↓	TLP or normal thrust	Takeoff thrust plus normal clean-up for go-around	Airspeed
9	Takeoff		↓	Down	Take-off	Take-off thrust	Gear up	Pitch attitude
10	↓		Minimum flap-retract speed	Up	Take-off	Take-off thrust	Retract high lift devices	Airspeed
11	Cruise	$h_{o_{min}}$ and $h_{o_{max}}$	Speed for level flight	Up	Up	MRT	Idle thrust	Pitch attitude
12				Up	Up	MRT	Actuate deceleration device	

TABLE XIII. Pitch Trim Change Conditions (cont.)

	Flight Phase	Initial Trim Conditions					Configuration Change	Parameter to be held constant
		Altitude	Speed	Landing Gear	High-lift Devices	Thrust		
13				Up	Up	MRT	Maximum augmented thrust	
14			Speed for best range	Up	Up	TLP	Actuate deceleration device	Altitude
15	Aerial Delivery	h_{omin}	V_{omax}	Up	As required	TLP	Open cargo door	Altitude & Airspeed
16	Aerial Delivery	h_{omin}	V_{omax}	Up	As required	TLP	Open jump door	Altitude & Airspeed
17	Low Altitude Aerial Delivery	h_{omin}	V_{omin}	Down	As required	TLP	Drop maximum weight cargo	Altitude & Airspeed

* Throttle setting may be changed during maneuver.

Notes: Auxiliary drag devices are initially retracted, and all details of configuration not specifically mentioned are normal for the Flight Phase.

- If power reduction is permitted in meeting the deceleration requirements established for the mission, actuation of the deceleration device in #12 and #14 shall be accompanied by the allowable power reduction.

** 3 and 4 also shall be investigated for V_{omax} and the approach flap shall be changed to landing flap deflection.

*** 6, 7 and 8 also shall be investigated for the landing flap deflection.

Discussion: Twenty pounds of trim force were allowed independent of controller type since values up to this were anticipated with certain configuration changes and were considered to be acceptable for the AMST. Values significantly greater than 20 pounds were experienced during the prototype flight testing and were not considered acceptable. Table XIII of the AMST specification was, in general, the same as Table XIV of the general MIL-F-8785B (Reference 1). Numbers 1 and 3 of Table XIII allowed thrust to be varied since that may be the manner in which the altitude is controlled near or on the backside of the power required curve. Numbers 3, 4, 6, 7, and 8 were expanded to investigate landing flaps since large trim forces may be associated with this configuration change. Numbers 3, 4, 6, 7, and 8 also recognized that sufficient thrust may not be available to fly constant altitude with the STOL landing flaps by addressing normal thrust as well as TLF. Number 14 was changed to altitude held constant to investigate the case where speed brakes are used to slow down during aerial refueling. A similar case should have been added to evaluate the use of drag devices to descend in altitude at constant speed. This maneuver was used tactically to quickly obtain approach conditions. Numbers 15, 16, and 17 were added to evaluate particular AMST mission requirements.

2.83 3.6.5 Delete.

Discussion: This paragraph from the general MIL-F-8785B (Reference 1) was changed to 3.2.3.2.3 in the AMST specification since it was more appropriate in the longitudinal control section for a STOL airplane.

2.84 3.7 Atmospheric Environment. This section presents the mean wind and turbulence models to be used for flight control system design. Sections 3.7.1 and 3.7.2 present models for continuous wind phenomena, mean wind and turbulence, and Section 3.7.3 presents the discrete gust model. For the continuous wind phenomena, wind and turbulence levels are defined by a probability of exceedence and altitude. For the low altitude models (below about 3,000 feet), the probability of exceedence defines a mean wind profile. This wind level then defines the turbulence levels. For high altitude operation (above about 3,000 feet), mean winds are not important for handling qualities so exceedence probabilities directly define turbulence levels and a mean wind model is not used. The continuous wind phenomena are generated in an earth-reference axis system, and transformed to the body-axis system. The calculation of airspeed is then:

TRANSLATIONAL

$$\begin{bmatrix} U_A \\ V_A \\ W_A \end{bmatrix} = \begin{bmatrix} U \\ V \\ W \end{bmatrix} + \begin{bmatrix} U_w \\ V_w \\ W_w \end{bmatrix} + \begin{bmatrix} U_t \\ V_t \\ W_t \end{bmatrix}$$

Body Inertial Mean Turbulence
Velocity Wind

RATIONAL

$$\begin{bmatrix} P \\ Q \\ R \end{bmatrix} = \begin{bmatrix} P \\ Q \\ R \end{bmatrix} + \begin{bmatrix} 0 \\ Q_t \\ R_t \end{bmatrix}$$

Body Inertial Turbulence
Velocity

Discussion: The atmospheric model for the AMST specification was different from the general MIL-F-8785B (Reference 1). The new model was selected because it was felt to be a better representation of the real world. The AMST model was formulated as a simplified version of the model reported in Reference 16. STOL airplanes are more susceptible to changes in flight path, angle of attack and airspeed when gusts and shears are encountered due mostly to flying on the backside of the power required curve and the lower approach speeds. Thus, it was felt necessary to model the gusts and shear characteristics accurately to determine actual STOL capability.

SECTION 3

CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations based on the development of flying qualities requirements for a production Advanced Medium STOL Transport (AMST) are presented below:

1. Flying qualities requirements were developed that addressed the major concerns of both STOL and conventional flight regions.

2. Requirements for acceptable open loop dynamics with the stability and command augmentation operating were felt to be weak and in need of further development, particularly in the longitudinal axis. The proposed criterion in Reference 9 should be applied to airplanes with AMST characteristics to determine if it could successfully determine flying qualities for that type of airplane. This criterion was developed to address higher order longitudinal flight control systems of fighter airplanes.

3. Requirements that address the combination of a rate command or attitude command system with attitude hold should be developed. The AMST flying qualities requirements addressed each of these modes individually; however, the pilot normally used the combination to control the airplane throughout the flight envelope. Acceptable flying qualities may not result from the combination even though the command and attitude hold modes meet their respective requirements.

4. Automatic reduction of control forces during mild maneuvering, such as normal terminal area operations, appeared to be acceptable. However, during tactical maneuvering near the airplane structural limits, the automatic reduction of control forces may be unacceptable due to the lack of stick force cues to warn of overstressing the airplane. This concern was not adequately addressed in the requirements presented in this report. It is recommended that stick forces not be allowed to be reduced to zero during tactical maneuvering until additional development work has been completed in this area.

5. The frontside or backside control technique (i.e., pitch column for flight path control and throttle for airspeed control, or vice versa) was acceptable to the AMST prototype pilots during STOL landing. Frontside control characteristics were provided artificially through augmentation. The effects of flight control system failures, particularly those that result in an unaugmented system, must be considered early in the design to insure good mission reliability during anticipated operational conditions.

6. Sizing the engine must take into account the flight path change capability required to track a glideslope in wind shears with an engine failed. The AMST requirements considered two different engine out situations; one where the engine failed below the go-around decision height and the other where the failure occurred above the decision height. A failure occurring above the go-around decision height was the critical case since higher wind magnitudes were considered. A decision must be made early in the STOL airplane development whether or not a STOL landing will be completed if an engine is known to be failed above the decision height, since this capability will have a direct impact on engine sizing and cost. Further, additional research on the flight path capability required for STOL landing must be conducted to provide more supporting data for this critical area.

7. As indicated in 6 above, the wind magnitudes and the corresponding wind shear profiles significantly affect STOL flight path tracking capability. The winds chosen for the AMST were based mostly on engineering judgment of what the operational situations would be like. It is likely that for other STOL airplane designs the wind magnitudes should be decreased or increased depending upon the anticipated operational conditions. Flight control system design, especially airspeed hold systems used during STOL landings, must consider the effects of wind shear profiles.

8. Many of the AMST requirements for the STOL flight region were based on limited flight test experience. The requirements should be revised, if necessary, as more flight test experience is gained.

APPENDIX

FLYING QUALITIES FOR C-1XA AIRPLANES

This appendix contains a complete set of the flying qualities requirements for a production AMST, and was released as part of the USAF Proposal Instruction Package in 1977.

III. FLYING QUALITIES FOR C-1XA AIRPLANES

1. SCOPE AND CLASSIFICATIONS

1.1 Scope. This document contains the requirements for the flying qualities of the C-1XA.

1.2 Application. These requirements shall be applied to assure that no limitations on flight safety or on the capability to perform intended missions will result from deficiencies in flying qualities.

1.3 Classification of Airplanes. Not required.

1.4 Flight Phase Categories. The Flight Phases have been combined into three categories which are referred to in the requirement statements. These Flight Phases shall be considered in the context of total missions so that there will be no gap between successive Phases of any flight and so that transition will be smooth. In certain cases, requirements are directed at specific Flight Phases identified in the requirement. When no Flight Phase or Category is stated in a requirement, that requirement shall apply to all three categories. Flight Phases descriptive of the C-1XA are:

Nonterminal Flight Phases:

Category A - Those nonterminal Flight Phases that require rapid maneuvering, precision tracking, or precise flight-path control. Included in this Category are:

- a. Low Altitude Aerial Delivery (LA).
- b. Close Formation Flying (FF).
- c. Contour Flying (CF)
- d. In-Flight Refueling (receiver) (RR).

Contour flying involves flight at altitudes up to 1000 feet above ground level to avoid ground fire or detection.

Category B - Those nonterminal Flight Phases that are normally accomplished using gradual maneuvers and without precision tracking, although accurate flight-path control may be required. Included in this Category are:

- | | |
|----------------|-------------------------|
| a. Climb (CL) | d. Descent (D) |
| b. Cruise (CR) | e. Deceleration (DE) |
| c. Loiter (LO) | f. Aerial Delivery (AD) |

Terminal Flight Phases:

Category C - Terminal Flight Phases normally requiring accurate flight path control.

- | | |
|-------------------------|-------------------------|
| a. Assault Takeoff (AT) | e. Assault Landing (AL) |
| b. Takeoff (TO) | f. Landing (L) |
| c. Approach (PA) | |
| d. Go-around (GA) | |

The word assault in this document is meant to signify that engine failed safety margins are not provided.

1.5 Levels of Flying Qualities. Where possible, the requirements of section 3 have been stated in terms of three values of the stability or control parameter being specified. Each value is a minimum condition to meet one of three Levels of acceptability related to the ability to complete the operational missions for which the airplane is designed. The Levels are:

- Level 1 Flying qualities clearly adequate for the mission Flight Phase
- Level 2 Flying qualities adequate to accomplish the mission Flight Phase, but some increase in pilot workload or degradation in mission effectiveness, or both exists.
- Level 3 Flying qualities such that the airplane can be controlled safely, but pilot workload is excessive or mission effectiveness is inadequate, or both. Category A Flight Phases can be terminated safely, and Category B and C Flight Phases can be completed safely.

2. Applicable Documents. Deleted.

3. Requirements.

3.1 General Requirements.

3.1.1 Operational Missions. The flying qualities throughout the operational missions defined in Appendix 10 of the System Specification shall meet the requirements of this document.

3.1.2 Loadings. The contractor shall define the envelopes of center of gravity and corresponding weights that can exist. These-

envelopes shall show the probable bounds of center of gravity that can exist for each Flight Phase. These envelopes shall include the most forward and aft center of gravity positions. In addition, the contractor shall determine the maximum center of gravity excursions attainable through failures in systems or components, such as fuel sequencing or hung payloads, for each Flight Phase to be considered in the Failure States of 3.1.6.2. Within these envelopes, including the excursions cited above, this document shall apply. A number of critical design loading envelopes shall be prepared within which the loadings for the various missions and Flight Phases fall.

3.1.3 Moments of Inertia. The contractor shall define the moments of inertia associated with all loadings of 3.1.2. The requirements of this document shall apply for all moments of inertia so defined.

3.1.4 External Stores. The requirements of this document shall apply for all combinations of external stores used during the operational missions. The effects of external stores on the weight, moments of inertia, center of gravity position, and aerodynamic characteristics of the aircraft shall be determined for each mission Flight Phase. When the stores contain expendable loads, the requirements of this document apply throughout the range of store loadings. In establishing external store combinations to be investigated, asymmetric as well as symmetric combinations shall be evaluated if these combinations are used during the operational missions.

3.1.5 Configurations. The requirements of this document shall apply for all configurations required or encountered in the applicable Flight Phases of 1.4. A (crew) selected configuration is defined by the positions and adjustments of the various selectors and controls available to the crew except for rudder, aileron, elevator, throttle and trim controls. Direct lift may be included in the configuration definition if it is not a third controller as defined in 3.2. The selected configurations to be examined must consist of those required for performance and mission accomplishment.

3.1.6 State of the Airplane. The State of the airplane is defined by the selected configuration together with the functional status of each of the airplane components or systems, thrust, weight, moments of inertia, and center of gravity position. The maximum/critical design weights and the corresponding moments of inertia shall be used in defining the State of the airplane. The trim settings and the control positions of the rudder, aileron, elevator, and direct lift (when considered as a third controller) are not included in the definition of Airplane State.

3.1.6.1 Airplane Normal States. The contractor shall define and tabulate all pertinent items to describe the Airplane Normal (no component or system failure) State(s) associated with each of the applicable Flight Phases. This tabulation shall be in the format and shall use the nomenclature as shown in 6.2. Certain items, such as weight, moments of inertia, center of gravity position, flap or thrust setting may vary continuously over a range of values during a Flight Phase. The contractor shall replace this continuous variation by a limited number of values of the parameter in question which will be treated as specific states, and which include the most critical states and the extremes encountered during the Flight Phase in question.

3.1.6.2 Airplane Failure States. The contractor shall define and tabulate all Airplane Failure States, which consist of failures of airplane components or systems that affect the Flying Qualities of the airplane. Failure States caused by more than three independent subsystem failures need not be tabulated. Airplane Failure States shall reflect changes in airplane hardware or the results of more detailed analyses. Examples would be jammed surfaces, mechanical or electrical disconnects, one or more channel of augmentation failed, and/or two hydraulic systems out. Other degradations or failure of airplane components for systems resulting from the first failure, must also be accounted for in determining the total effects on aircraft control. More specific direction is given in 3.1.10.2.

3.1.6.2.1 Airplane Special Failure States. Certain components, systems, or combinations thereof, may have extremely remote probability of failure during a given mission. These failure probabilities may, in turn, be very difficult to predict with any degree of accuracy. Special Failure States of this type need not be considered in complying with the requirements of section 3 (except 3.1.10.2) if justification for considering the Failure States as special is submitted by the contractor. The Airplane Special Failure States shall reflect changes in airplane hardware or the results of more detailed analyses. Failures which have a probability of occurrence less than 1×10^{-9} per mission may be considered Special Failure States without submittal to the procuring activity.

3.1.7 Operational Flight Envelopes. The Operational Flight Envelopes define the boundaries in terms of speed, altitude, and load factor within which the airplane must be capable of operating in order to accomplish the missions of 3.1.1. These envelopes shall be defined for the atmospheric temperatures required by paragraph 3.2 of the System Specification and Appendix 50 of the System Specification. Envelopes for each applicable Flight Phase shall be established by the contractor. The boundaries of the Operational Flight Envelopes shall be as defined by paragraphs 3.1.7.1, 3.1.7.2, 3.1.7.3, and 3.1.7.4.

3.1.7.1 Maximum Operational Speed. The maximum operational speed (V_{omax}) for each Flight Phase shall be established by the contractor. These speeds shall be compatible with the operational missions and performance requirements of the System Specification.

3.1.7.2 Minimum Operational Speed. The minimum operational speed (V_{omin}) shall be low enough that the operational missions and performance requirements of the System Specification can be achieved. The minimum operational speeds shall not be greater than those shown in Table I for each Flight Phase. In addition, it must be possible for the airplane to encounter a 20 knot upgust at the selected minimum operational speed without exceeding the stall angle of attack (α_s), with all engines operating. For the critical engine inoperative, the requirement is to penetrate a 15 knot upgust. Trim control settings shall not be changed by the crew for these gust encounters.

TABLE I Upper Limits for Minimum Operational Speeds

Flight Phase Category	Flight Phase	V_{omin}
A	Low Altitude Aerial Delivery (LA) Close Formation Flying (FF) Contour Flying (CF) In-Flight Refueling (receiver) (RR)	# 1.6 V_s 1.6 V_s 1.6 V_s
B	Climb (CL) Cruise (CR) Loiter (LO) Descent (D) Deceleration (DE) Aerial Delivery (AD)	0.85 $V_{r/c}$ 0.85 V_{range} 0.85 V_{end} 1.4 V_s 1.4 V_s 1.2 V_s
C	Assault Takeoff (AT) Takeoff (TO) Approach (PA) Go-Around (GA) Assault Landing (AL) Landing (L)	* 1.2 V_s 1.2 V_s 1.2 V_s * 1.2 V_s

The minimum speed for zero degrees deck angle minus 10 knots, but not less than 1.2 V_s

*The minimum speeds for these Flight Phases should be defined by the contractor.

3.1.7.3 Maximum Operational Altitude. The maximum operational altitude for each Flight Phase shall be established by the contractor. These altitudes shall be compatible with the operational missions and performance requirements of the System Specification.

3.1.7.4 Operational Load Factors. The maximum (minimum) operational load factor is the lowest (highest) algebraically of the following:

- a. $n = 2.0$ ($n = 0.5$).
- b. The load factor at which stall warning occurs.

The maximum and minimum operational load factors for each Flight Phase shall be established as a function of speed for several different altitudes.

3.1.8 Service Flight Envelopes. For each Airplane Normal State the contractor shall establish Service Flight Envelopes showing combinations of speed, altitude, and normal acceleration derived from airplane limits as distinguished from mission requirements. These envelopes shall be defined for the atmospheric temperatures required by paragraphs 3.2 of the System Specification and Appendix 50 of the System Specification. For each applicable Flight Phase and Airplane Normal State, the boundaries of the Service Flight Envelopes can be coincident with or lie outside the corresponding Operational Flight Envelope, but in no case shall they fall inside those Operational boundaries. The boundaries of the Service Flight Envelopes shall be based on 3.1.8.1, 3.1.8.2, 3.1.8.3, and 3.1.8.4.

3.1.8.1 Maximum Service Speed. The maximum service speed, V_{max} or M_{max} , for each altitude shall be the same as the maximum operational speed. An acceptable speed margin shall exist between the maximum service speed and the maximum permissible speed, with the high-lift devices stored, to allow for inadvertent overspeed conditions. When the high-lift devices are extended, the maximum service speed may be the same as the maximum permissible speed.

3.1.8.2 Minimum Service Speed. The minimum service speed, V_{min} or M_{min} , for each altitude is the highest of:

- a. $1.1 V_S$
- b. $V_S + 10$ knots equivalent airspeed.
- c. Stall warning speed defined by 3.4.2.1.1, for any thrust setting.
- d. A speed at which it is possible to achieve a constant heading following a sudden asymmetric loss of takeoff thrust from the most critical factor, and thereafter to maintain a constant heading. No changes in the

pilot selected configuration are allowed to show compliance with this requirement. In addition, at this speed the roll control capability shall provide at least 30 degrees bank angle change in 4 seconds. The roll requirement shall be met for the steady state symmetric thrust condition, with takeoff thrust maintained on the operative engine(s), and trim at normal settings for symmetric thrust. The airplane may be banked up to 5 degrees in a direction to assist control.

e. A speed limited by reducing visibility or an extreme pitch attitude that would result in the tail or aft fuselage contacting the ground.

3.1.8.3 Maximum Service Altitude. The maximum service altitude, h_{max} , for a given speed is the maximum altitude at which a rate of climb of 100 feet per minute can be maintained in unaccelerated flight with take-off thrust.

3.1.8.4 Service Load Factors. Maximum and minimum service load factors, $n(+)$ ($n(-)$), shall be established as a function of speed for several significant altitudes and weights. No consideration is given to the power required to maintain flight at these g levels. The maximum (minimum) service load factor, when trimmed for lg flight at a particular speed and altitude, is the lowest (highest) algebraically of:

a. The positive structural limit load factor, or for negative load factor to zero g's.

b. The load factor corresponding to stall warning (3.4.2.1.1).

c. A safe margin below (above) the load factor at which intolerable buffet or structural vibration is encountered.

3.1.9 Permissible Flight Envelopes. The Permissible Flight Envelopes encompass all regions in which operation of the airplane is possible. These are the boundaries of flight conditions outside the Service Flight Envelope which the airplane is capable of safely encountering. The Permissible Flight Envelopes define the boundaries of these areas in terms of speed, altitude, and load factor. These envelopes shall be defined for the atmospheric temperatures required by paragraph 3.2 of the System Specification and Appendix 50 of the System Specification.

3.1.9.1 Maximum Permissible Speed. The maximum permissible speed for each altitude shall be the lowest:

a. Limit speed based on structural considerations.

b. Limit speed based on engine considerations.

c. The speed at which intolerable buffet or structural vibrations is encountered.

d. The speed at which the transonic Mach tuck is greater than allowed for Level 3 of paragraph 3.2.1.1.1.

3.1.9.2 Minimum Permissible Speed (V_s). The minimum permissible speed for a specified configuration shall be the highest of:

- a. Speed, with constant heading angle, for flight at CL_{max} (the first local maximum of the lift coefficient vs angle of attack which occurs as CL is increased from zero).
- b. Speed at which uncontrollable pitching, rolling or yawing occurs; i.e., loss of control about a single axis.
- c. Minimum demonstrated speed-due to intolerable buffet, structural vibration, angle of attack effects, or an excessive rate of sink.

The minimum permissible speed shall be determined for:

- a. 1g normal to the flight path.
- b. Approach to stall at $\frac{1}{2}$ knot to 1 knot per second.
- c. Most unfavorable center of gravity.
- d. Out of ground effect.
- e. The following condition that results in the highest minimum permissible speed for each flight phase. Assault takeoff and assault landing are excluded from this consideration.

<u>Flight Phase</u>	<u>Thrust Control Setting</u>	<u>All Engines Operating (AEO) / Critical Engine Inoperative (CEI)</u>
Takeoff	Takeoff	AEO and CEI
Approach/Landing	Takeoff	CEI
Approach/Landing	Approach	AEO
Go-Around	Go-Around	AEO and CEI
Descent/ Deceleration	Minimum Allowable*	AEO and CEI
All Other	TLF at 1.2 V_s	AEO and CEI

*Minimum allowable includes reverse thrust.

3.1.9.3 Maximum Permissible Altitude. The maximum permissible altitude is that corresponding to zero rate of climb.

3.1.9.4 Permissible Load Factors. The maximum (minimum) permissible normal load factor is the lowest (highest) of the following:

- a. The positive (negative) structural limit load factor.
- b. The load factor corresponding to stall.
- c. The normal load factor at which intolerable buffet or structural vibration is encountered.

3.1.10 Applications of Levels. Levels of flying qualities as indicated in 1.5 are employed in this document in realization of the possibility that the airplane may be required to operate under abnormal conditions. Such abnormalities that may occur as a result of either flight outside the Operational Flight Envelope or the failure of airplane components, or both, are permitted to comply with a degraded Level of flying qualities as specified in 3.1.10.1 through 3.1.10.3.3.

3.1.10.1 Requirements for Airplane Normal States. The minimum required flying qualities for Airplane Normal States (3.1.6.1) are as shown in Table II.

TABLE II. Levels for Airplane Normal States

Within Operational Flight Envelope	Within Service Flight Envelope
Level 1	Level 2

3.1.10.2 Requirements for Airplane Failure States. When Airplane Failure States exist (3.1.6.2), a degradation in flying qualities is permitted. The contractor shall determine, based on the most accurate available data, the probability of occurrence of each Airplane Failure State per mission and the effect of the Failure State on the flying qualities within the Operational and Service Envelope. Specifically, the analysis shall address the following: (a) The ~~Wartime Logistic Resupply Airland~~ ^{T&D} Profile defined in the System Specification, Appendix, Section 60, Table ~~60-4~~ ^{T&D} shall be used for this analysis. This mission scenario will be used to determine how long specific aircraft systems are used per mission. (b) All of the various elements that can fail in many different modes but result in the same general airplane condition shall be tabulated under one general failure state (e.g., pitch augmentation failure, force gradient reduction, one hydraulic system out, etc.). The probability of encountering the general failure state shall be calculated as a function of all the element failures. Once the effect of a general failure state on handling qualities is determined (see part c), the probability of encountering a particular Level of handling qualities is also known for a particular general failure state. (c) The effect of a general failure

state on handling qualities in calm air must be determined by either analytical comparison of the degraded performance with quantitative requirements stated herein, or pilot opinion from simulation studies investigating a particular failure(s).

(d) The probability, per mission, of encountering Level 2 shall include the probability of all the general failure states in which the Flying Qualities are worse than Level 2. (e) The probability, per mission, of encountering Level 3 shall include the probability of all the general failure states in which the Flying Qualities are worse than Level 3 and are unsafe. (f) The probability of encountering Flying Qualities Levels 2 or 3 shall include special failure states, if the probability can be calculated. (g) Each general failure state is assumed to be present at whichever point in the flight envelope that is most critical from a handling qualities point of view. (h) Random failures which result in Level 3 or below flying qualities at the altitudes and airspeeds of the missions of System Specification, Appendix 60, shall be assumed to result in mission abort. These aborts shall be included in the C-1XA mission reliability analysis. (i) Encountering below Level 3 flying qualities will be assumed to be a safety consideration, and shall be included in the C-1XA mission safety analysis.

The probabilities of encountering lower Levels of flying qualities due to failures shall be less than the values shown in Table III.

TABLE III. Levels for Airplane Failure States

Probability of Encountering	Within Operational Flight Envelope	Within Service Flight Envelope
Level 2 After Failure	$<10^{-2}$ per mission	
Level 3 After Failure	$<10^{-4}$ per mission	$<10^{-2}$ per mission

In no case shall a Failure State, except an approved Special Failure State, degrade any flying quality parameter outside the Level 3 limit. All flight control system failure states that result in below Level 3 Flying Qualities shall not have a cumulative failure probability of greater than 5×10^{-7} per mission. These failure states are excluded from the requirement to be submitted to the procuring activity.

3.1.10.2.1 Requirements for Specific Failures. Specific types of failures and the Level of flying qualities that results in each Envelope from the failure are listed. These Levels of flying qualities shall be met on the basis that the specific type of failure has occurred, regardless of its probability of occurrence. The listed failures shall be analyzed separately, and with the failures occurring in flight except for items 3 and 6. Possible crew corrective action may be initiated after an appropriate time delay.

Failure State	Flying Quality Level Within This Flight Envelope		
	Operational	Service	Permissible
1. Complete loss of Electronic Flight Control System (All electrical power failed).	3	3	-
2. Failure of most critical high lift surface to deploy or retract	2	3	-
3. Takeoff with a flat tire.	2	3	-
4. Failure of in-flight deceleration device to deploy or retract.	2	3	-
5. Failures associated with rapid decompression	3	-	-
6. Critical engine inoperative takeoff as defined in 3.2.1.4.2 of the System Specification.	2	3	-

3.1.10.3 Exceptions.

3.1.10.3.1 Ground Operation and Terminal Flight Phases. When requirements are stated for ground operation such as taxiing, takeoff acceleration run, or landing deceleration rollout; or for transition from minimum liftoff speed to minimum operational speed; or from minimum operational speed to minimum touchdown speed, the required Levels shall be applied as if the conditions were in the Operational Flight Envelope

3.1.10.3.2 When Levels are not Specified. Deleted.

3.1.10.3.3 Flight Outside the Service Flight Envelope. It shall be readily possible to safely return to the Service Flight Envelope from all points in the Permissible Flight Envelopes without exceptional pilot skill or technique. Special Failure States and Specific Failure States which do not have a design requirement in the Permissible Envelope are excluded. The requirements on flight at high-angle-of-attack, dive characteristics, dive recovery devices, and dangerous flight conditions shall also apply.

3.1.11 Interpretation of Quantitative Requirements. Deleted.
(Have moved this paragraph to Section 4, 4.2).

3.1.12 Assault Mode of Operation. Maximum use of power lift effects for airplane performance can be achieved by reducing the normal speed and control margins provided to account for failures. If this reduced margin region is utilized, a minimum of Level 2 handling qualities must be provided prior to failure occurrence.

3.2 Longitudinal Flying Qualities. Two primary longitudinal controllers are allowed. A third controller may be used if the pilot does not have to remove his hand(s) from the primary controller(s) to operate it. Contractor must define what primary airplane response is expected from each controller. If the response varies with airspeed, flap angle, etc., this must be defined.

3.2.1 Longitudinal Stability.

3.2.1.1 Longitudinal Static Stability. There shall be no tendency for the airspeed to diverge aperiodically when the airplane is disturbed from trim due to external disturbances with the cockpit controls fixed and with them free, except as allowed by 3.2.2.1.2. For airplane states that include automatic reduction of pilot control forces for steady state variations in speed or load factors, stable or neutral elevator control force and elevator control position with airspeed and load factor may be provided. The automatic reduction of forces shall not result in any reversal of the pilot's control force (i.e., from push to pull or vice versa).

For all other airplane states this requirement will be considered satisfied if the variations of elevator control force and elevator control position with airspeed are smooth and the local gradients stable with: Trimmer and throttle controls not moved from the trim settings by the crew and lg acceleration normal to the flight path, and constant altitude over a range about the trim speed of ± 15 percent or ± 50 knots equivalent airspeed, whichever is less (except where limited by the boundaries of the Service Flight Envelope).

Stable gradients mean increasing pull forces and aft motion of the elevator control to maintain slower airspeeds and the opposite to maintain faster airspeeds. Neutral gradients mean zero pull forces and no motion of the elevator control to maintain slower or faster airspeeds. The term gradient does not include that portion of the control force or control positions versus airspeed curve within the pre-loaded breakout force or friction range.

3.2.1.1.1 Relaxation in Transonic Flight. The requirements of 3.2.1.1 may be relaxed in the transonic speed range provided any divergent airplane motions or reversals in slope of elevator control force and elevator control position with speed are gradual and not objectionable to the pilot. In no case, however, shall the requirements of 3.2.1.1 be relaxed more than the following: a. Levels 1 and 2 - For center-stick controllers, no local force gradient shall be more unstable than 3 pounds per 0.01 M nor shall the force change exceed 10 pounds in the unstable direction. The corresponding limits for wheel controllers are 5 pounds per 0.01 M and 15 pounds, respectively. b. Level 3 - For center-stick controllers, no local force gradient shall be more unstable than 6 pounds per 0.01 M nor shall the force ~~ever~~ exceed 20 pounds in the unstable direction. The corresponding limits for wheel controllers are 10 pounds per 0.01 M and 30 pounds, respectively. This relaxation does not apply to Level 1 for any Flight Phase which requires prolonged transonic operation.

3.2.1.1.2 Elevator Control Force Variations During Rapid Speed Changes. When the airplane is accelerated and decelerated rapidly through the operational speed range by the most critical combination of changes in power, actuation of deceleration devices, steep turns and pullups, the magnitude and rate of the associated trim change shall not be so great as to cause difficulty in maintaining the desired load factor by normal pilot techniques.

3.2.1.2 Phugoid Stability. The long-period airspeed oscillations which occur when the airplane seeks a stabilized airspeed following a disturbance shall meet the requirements of paragraph 3.2.2.1.2.

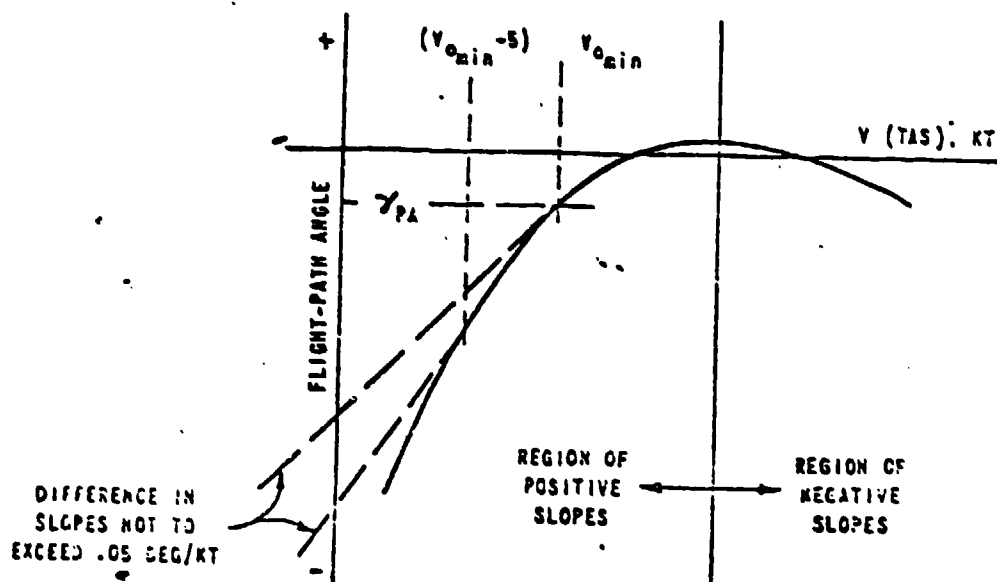
3.2.1.3 Hands on Flight-Path Stability. Flight-path stability is defined in terms of flight-path-angle change where the airspeed is changed by the use of the elevator control only (throttle and flap setting not changed by either the crew or automatic devices). Specifically, this requirement is applicable when an airspeed hold mode as defined in 3.2.5 is not functioning. Conversely this requirement is not applicable when a speed hold mode is functioning. For the Landing Flight Phase and when the longitudinal column is used chiefly for rapid flight path control, the steady state flight-path-angle versus steady state true-airspeed curve shall have a local slope at V_{0min} which is negative or less positive than:

- a. Level 1 ----- 0.06 degrees/knot
- b. Level 2 ----- 0.15 degrees/knot
- c. Level 3 ----- 0.24 degrees/knot

When a primary controller other than the longitudinal column is used to effect a rapid change in flight path, the local slope at V_{min} shall be negative or less positive than:

- a. Level 1 . . . 0.20 degrees/knot
- b. Levels 2 and 3 . . . 0.35 degrees/knot

In either case, the thrust setting shall be that required for the normal approach glide path at V_{min} . The slope of the flight-path angle versus airspeed curve at 5 knots slower than V_{min} shall not be more than 0.05 degrees per knot more positive than the slope at V_{min} , as illustrated by:



3.2.1.3.1 Hands Off Flight-Path Stability. For Level 1, the airplane with cockpit controls free shall tend to return to the trimmed γ , if it is perturbed from a trimmed flight condition by any momentary input other than commanded steady state changes in speed or flight path (γ).

3.2.1.4 Pitch Attitude Versus Flight Path Angle. For the Landing Flight Phase, the ratio of the steady state attitude change to flight path angle change ($\Delta\theta/\Delta\gamma$) at constant airspeed for column inputs, for airplanes that use the longitudinal column for rapid flight path control, shall be as follows:

Level	$\Delta\theta/\Delta\gamma$	
	Min	Max
1	0.75	1.5
2	0.5	1.5

3.2.1.5 Velocity Change Versus Flight Path Angle. For the Landing Flight Phase with maximum flap deflection, the slope of the steady state velocity change to flight path angle change ($\Delta u/\Delta\gamma$), at constant pitch attitude, and with variation of thrust about the trim approach thrust setting, shall be near the value of zero for Level 1 and 2. This requirement applies to airplanes that do not use the longitudinal column for rapid flight path control and at the minimum operational speed.

3.2.2 Longitudinal Maneuvering Characteristics.

3.2.2.1 Longitudinal Response. Requirements for the responses of angle of attack, pitch rate, load factor, and airspeed which are produced by abrupt pilot inputs of the appropriate primary controller(s), are addressed by 3.2.2.1.1 and 3.2.2.1.2. These requirements apply with the cockpit controls fixed and with them freed, after the input is made, for responses of any magnitude that might be experienced in normal service use. If oscillations are nonlinear with amplitude, the requirements shall apply to each cycle of the oscillation. For Normal States with a pitch attitude hold mode as defined in 3.2.7, these requirements do not apply when the airplane is within the static accuracy band of ± 0.5 degrees defined in 3.2.7.

3.2.2.1.1 Short-Term Frequency and Acceleration Sensitivity. The short term natural frequency response of angle of attack, pitch rate and load factor at constant airspeed for the total airplane aerodynamics, flight controls, augmentation and propulsion system shall be similar to a second order response and shall be within the limits shown in Figures 1, 2, and 3. The Level 3 lower bounds on ω_{nsp} and n/a of Figure 3 may be relaxed if compliance is shown with the requirements of 3.2.2.1.4. Note that the n/a to show compliance with this requirement is due only to the movement of the longitudinal column.

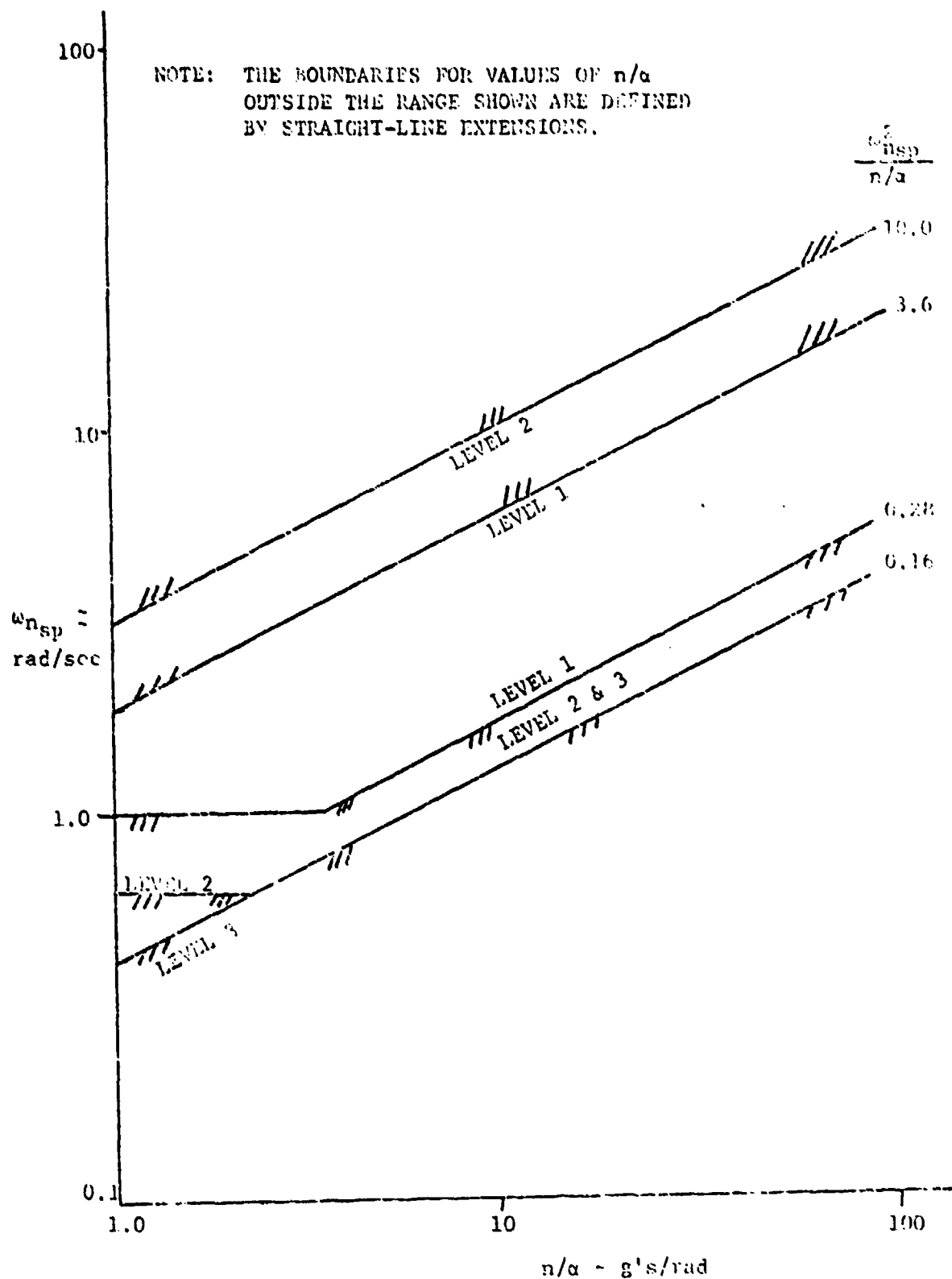


Figure 1. SHORT-TERM FREQUENCY REQUIREMENTS - CATEGORY A FLIGHT PHASES

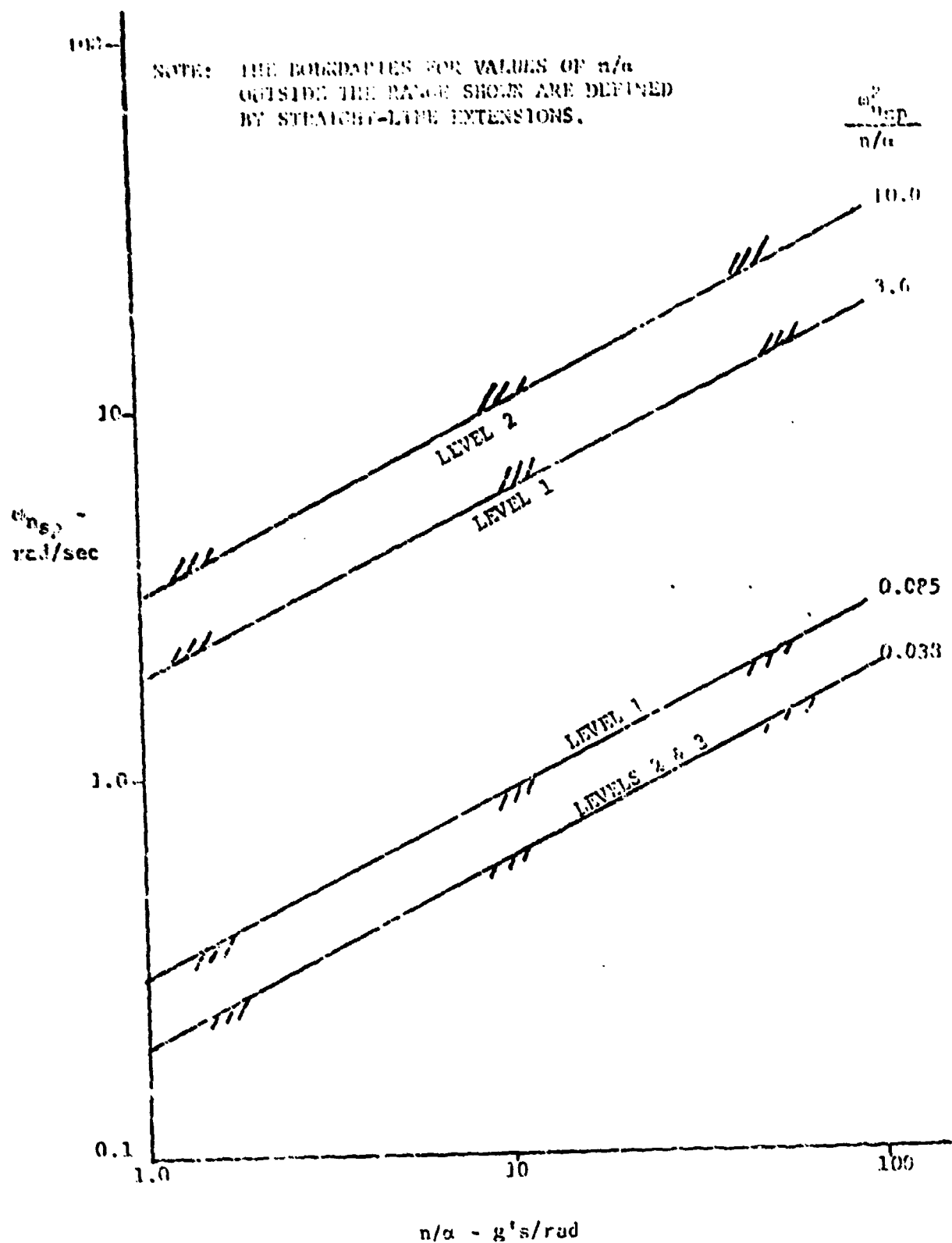


Figure 2. SHORT-PERIOD FREQUENCY REQUIREMENTS - CATEGORY B FLIGHT PHASES

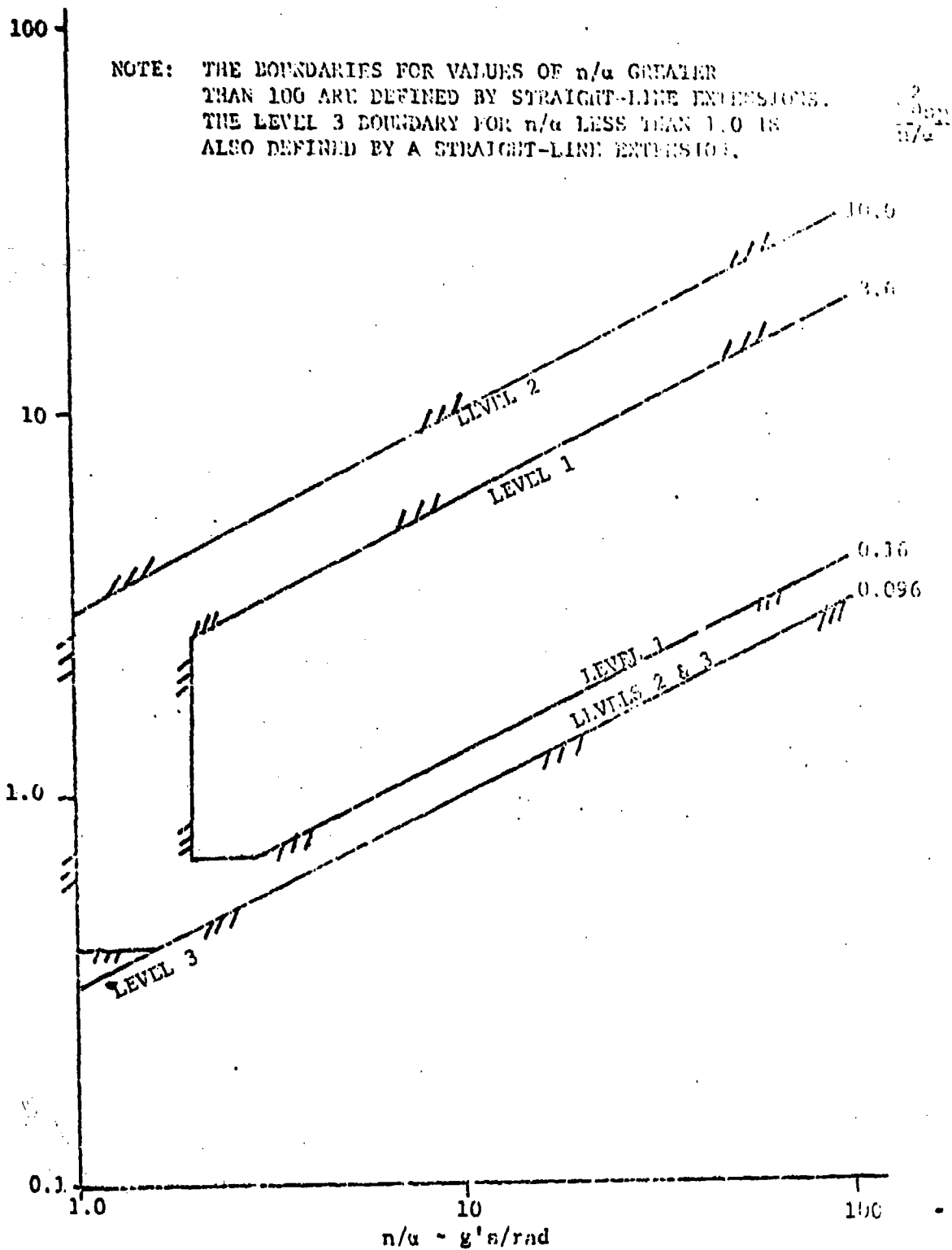


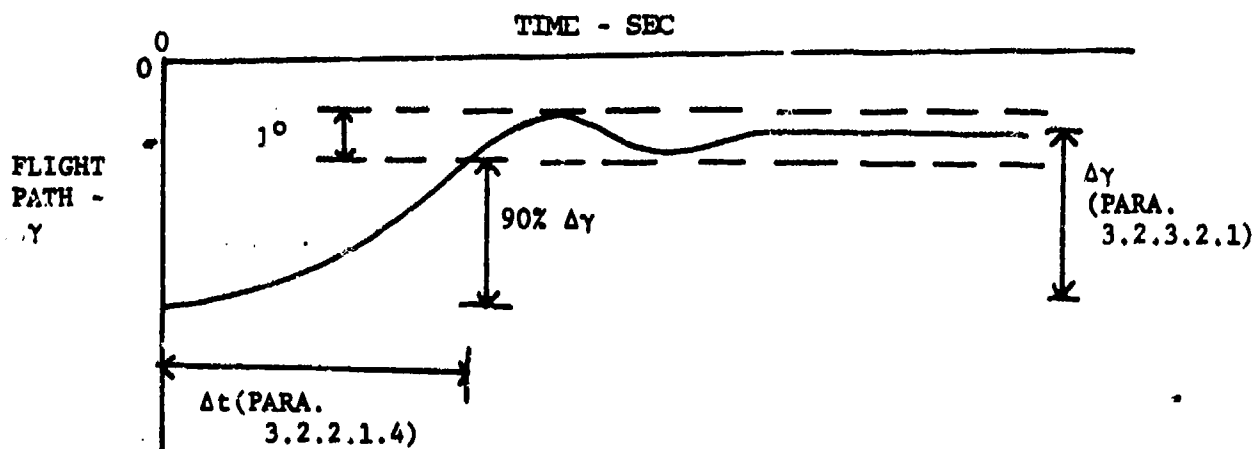
Figure 3. SHORT-PERIOD FREQUENCY REQUIREMENTS - CATEGORY C FLIGHT PROFILES

3.2.2.1.2 Total System Damping. All longitudinal characteristic roots due to airplane aerodynamics, flight controls, augmentation, and propulsion system which affect angle of attack, pitch rate, load factor and airspeed response shall have damping that complies with Figure 4 for all Categories. The maximum damping ratio for the short term response shall be 1.3 and 2 for Levels 1 and 2, respectively.

The Levels 2 and 3 requirements may be relaxed, as shown by the dashed lines on Figure 4, for cases where 3.2.1.1.1 permits relaxation of the static stability requirement (3.2.1.1) and for the Landing and Go-Around Flight Phases. In no case, however, shall the flight conditions that result in a characteristic root in this relaxed area be sustained for more than 5 minutes.

3.2.2.1.3 Residual Oscillations. Any sustained residual oscillations shall not interfere with the pilot's ability to perform the tasks required in service use of the airplane. For Levels 1 and 2, oscillations in normal acceleration at the pilot's station greater than ± 0.02 g's will be considered excessive for any Flight Phase.

3.2.2.1.4 Flight Path Response. The time response of the flight path angle changes in the Landing Flight Phase required by 3.2.3.2.1 shall be smooth. Ninety percent (90%) of the required change in flight path angle at the minimum operational speed shall be obtained in less than 5 seconds, and at the speeds above and below the minimum operational speed, ninety percent of the flight path angle change must be obtained in less than 3 seconds after the pilot command. Following these time periods, the flight path angle shall remain within ± 0.5 degrees about the steady state value. The figure below illustrates this requirement. This requirement defines Level 1.



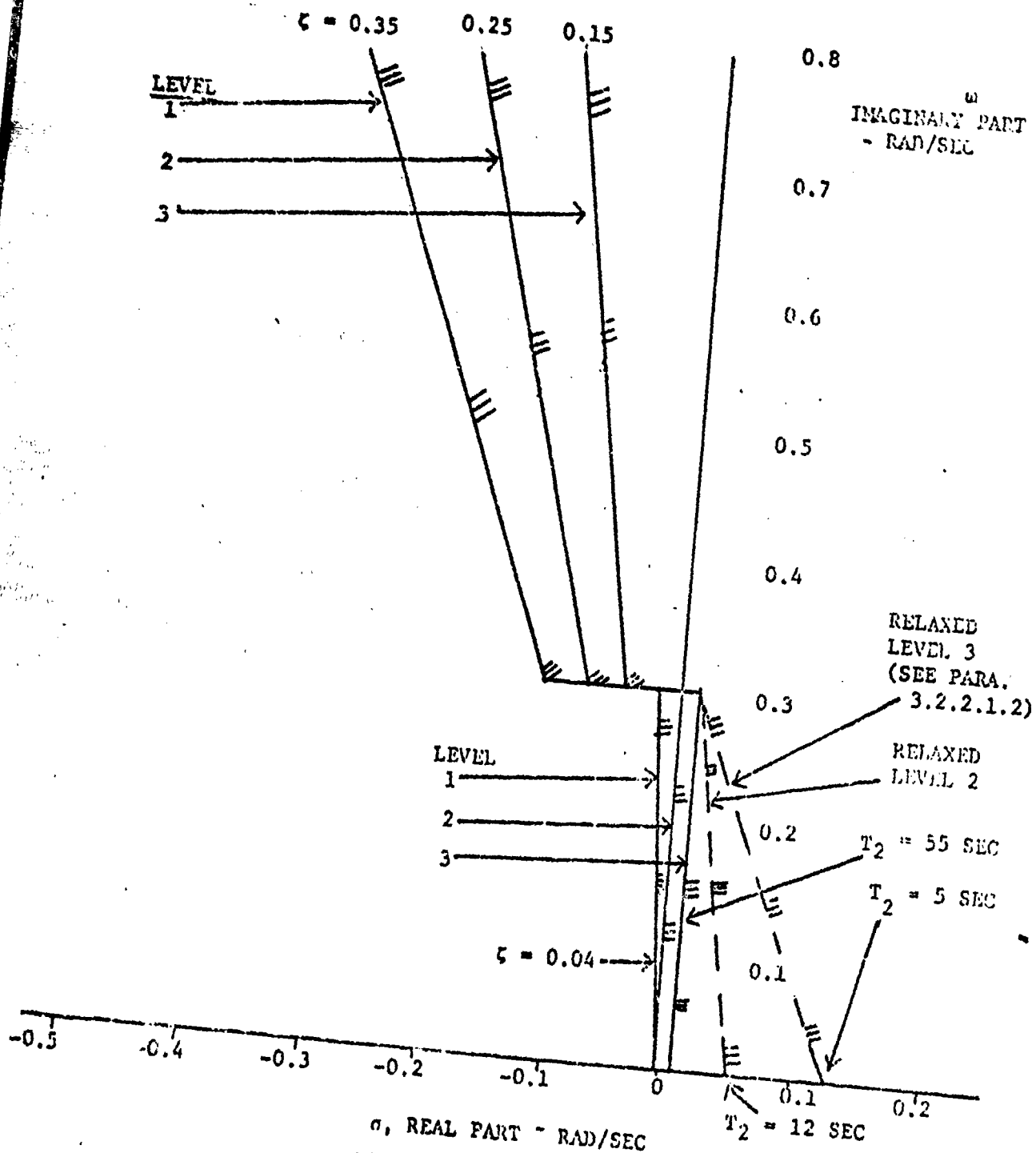


FIGURE 4. SYSTEM DAMPING

3.2.2.2 Control Feel and Stability in Maneuvering Flight. In steady turning flight and in pull-ups at constant speed, the elevator control force and elevator control deflection required to maintain a change in normal acceleration shall be in the same sense as those required to initiate the load factor change; that is, airplane-nose-up control inputs to maintain an increase in normal acceleration, airplane nose-down control inputs to maintain a decrease in normal acceleration. These requirements apply to local gradients in constant-airspeed maneuvers throughout the range of service load factors defined in 3.1.8.4. This requirement applies for Levels 1 and 2.

3.2.2.2.1 Control Forces in Maneuvering Flight. At constant speed in pullups and pushovers, the variations in elevator-control force with steady-state normal acceleration shall be approximately linear. A departure from linearity resulting in a local gradient which differs from the average gradient for the maneuver by more than 50 percent is considered excessive within the Operational and Service Envelopes. All local force gradients shall be within the limits of Table IV. The term gradient does not include that portion of the force versus load factor curve within the preloaded breakout force or friction band. With Normal States that include automatic reduction of pilot control forces for steady state changes in load factor, the gradients of Table IV do not apply.

3.2.2.2.2 Control Motions in Maneuvering Flight. The elevator-control motions in maneuvering flight shall not be so large or so small as to be objectionable. For Category A Flight Phases, the average gradient of elevator-control force per inch of elevator-control deflection at constant speed shall be not less than 5 pounds per inch for Levels 1 and 2.

3.2.2.3 Longitudinal Pilot-Induced Oscillations. There shall be no tendency for pilot-induced oscillations that are sustained or uncontrollable resulting from the efforts of the pilot to control the airplane. This requirement and 3.2.2.3.1 apply for Levels 1, 2, and 3.

3.2.2.3.1 Transient Control Forces. The peak elevator-control forces developed during abrupt maneuvers at constant speed shall not be objectionably light, and the buildup of control force during the maneuver entry shall lead the buildup of normal acceleration. Specifically, the following requirement shall be met when the elevator control is pumped sinusoidally. For all input frequencies up to structural mode frequencies the ratio of the peak force amplitude to the peak normal load factor amplitude at the center of gravity, measured from the steady oscillation, shall be greater than 3.0 pounds per g.

TABLE IV. Elevator Maneuvering Force Gradient Limits

<u>Center Stick Controllers</u>		
Level	Maximum Gradient, $(F_s/n)_{\max}$, pounds per g	Minimum Gradient, $(F_s/n)_{\min}$, pounds per g
1	28.0	10.5
2	42.5	9.0
3	56.0	3.0

<u>Wheel Controllers</u>		
Level	Maximum Gradient, $(F_s/n)_{\max}$, pounds per g	Minimum Gradient, $(F_s/n)_{\min}$, pounds per g
1	60.0	20.0
2	91.0	19.0
3	240.0	6.0

3.2.3 Longitudinal Control.

3.2.3.1 Longitudinal Control in Unaccelerated Flight. In unaccelerated flight at all service altitudes, the attainment of all speeds between V_S and V_{max} shall not be limited by the effectiveness of the longitudinal control, or controls. This requirement applies for Levels 1 and 2.

3.2.3.2 Longitudinal Control in Maneuvering Flight. Within the Operational Flight Envelope speed range it shall be possible, except where limited by stall or structural limits, to develop the following range of load factors by use of the primary longitudinal control surface alone:

LEVEL	n_{Cmax}	n_{Cmin}
1	3.0	0.0
2	2.0	0.25
3	1.25	0.75

This maneuvering capability is required at the 1g trim speed and over a range about the trim speed the lesser of ± 15 percent or ± 50 knots equivalent airspeed at constant altitude (except where limited by the boundaries of the Operational Flight Envelope). Trim and throttle settings shall not be changed by the crew. Within the Service and Permissible Flight Envelopes, the dive-recovery requirements of 3.2.3.5 and 3.2.3.6, respectively shall be met.

3.2.3.2.1 Flight Path Angle Change Capability Required for Landing on Tactical Mobility Mission Runway (Paragraph 3.2.1.1 of the System Specification). For the Landing Flight Phase, the required steady state changes in flight path angle ($\Delta\gamma$) about the initially trimmed approach glide slope at constant speed and in calm air are defined as follows:

Speed	$\Delta\gamma$ (deg)-All Engines Operating
V_{Omin}	Level Flight and -4.0
$V_{Omin} + 5kts$	-2.0
$V_{Omin} - 5kts$	+2.0

Sufficient excess thrust shall exist at V_{Omin} in the landing configuration to land on the runway following loss of thrust of one engine at or below the engine-out go-around decision height (as determined by Combined

Test Team) without manually reconfiguring the airplane. This shall be accomplished in a total wind of at least 16 knots as defined by Figure 7/1 with the shears and turbulence defined respectively in 3.7.1 and 3.7.2.2, and with a surface roughness length of 0.15. Maximum crosswind and tailwind components shall be at least 12 knots and 6 knots, respectively, measured at 20 feet. A realistic pilot reaction time shall be used. The landing flap deflection may be established on the basis of airplane weight and wind component. It shall be assumed that the airplane is on the planned approach path to the desired touchdown aim point at the scheduled approach speed when the failure occurs. The touchdown aim point is in the center of the touchdown zone which is defined as the distance the airplane is in the air using the landing performance rules given in Section 50.3 of the System Specification.

For landings made at the field with an engine failed, where the engine failure has occurred above the engine-out go-around decision height, sufficient excess thrust shall exist at V_{min} that the normal approach flight path angles can be maintained. This shall be accomplished in a total wind of at least 23 knots as defined by Figure 7/1 with the shear and turbulence defined respectively in 3.7.1 and 3.7.2.2, and with a surface roughness length of 0.15. Maximum crosswind and tailwind components shall be at least 19 knots and 10 knots, respectively, measured at 20 feet. The landing flap deflection selected for engine-out landing approaches may be established as a function of weight and wind component. To satisfy this requirement, a flight path angle change capability of ± 2 degrees in calm air is required in addition to that required to maintain normal approach flight path angles in the above stated winds, shears and turbulence. No manually commanded configuration changes are permitted.

The above capabilities must be demonstrated for the weight at the midpoint of the Tactical Mobility Mission defined in the System Specification, 103°F hot day air temperature, and at sea level.

Thrust reductions to stall warning are permitted to demonstrate the required negative changes in flight path angle. For this requirement all aircraft systems shall be functioning normally, except for the failed engine.

3.2.3.2.1.a Landing in Turbulence. Level 1 flying qualities are required for a landing on the short field defined in paragraph 3.2.1.1 of the System Specification in a total wind of at least 25 knots as defined in 3.7.1, Figure 7/1. The shears and turbulence corresponding to this total wind shall also be considered and are defined in 3.7.1 and 3.7.2.2, respectively, using a surface roughness length of 0.15. For this requirement, maximum crosswind and tailwind components shall be at least 25 knots and 10 knots respectively, measured at 20 feet.

All airplane systems are assumed to be operating normally. The weight at the midpoint of the Tactical Mobility Mission defined in the System Specification, 103°F hot day air temperature, and at sea level shall be used for the analysis.

3.2.3.2.2 Turn Rate. During the Landing Flight Phase, at the maximum possible pilot selected flap deflection (contractor may specify specific number), a constant turn rate of 7.5 degrees per second is required for Level 1 at the minimum operational speed and on the trimmed approach glide slope. This condition shall be demonstrated for the weight at the midpoint of the Tactical Mobility Mission defined in the System Specification 103°F hot day air temperature, all engines operating and at sea level.

3.2.3.2.3 Direct Normal-Force Control. Use of devices for direct normal force control shall not produce objectionable changes in attitude for any amount of control up to the maximum available. This requirement shall be met for Levels 1 and 2 and shall be safe for Level 3.

3.2.3.3 Longitudinal Control in Takeoff. The effectiveness of the elevator control shall not restrict the takeoff performance required of the airplane and defined in the System Specification, and shall be sufficient to prevent over-rotation to undesirable attitudes during takeoffs. Satisfactory takeoffs shall not be dependent upon use of the trimmer control during takeoff or on complicated control manipulation by the pilot. These requirements shall be met on hard-surfaced runways and unprepared fields that are specified in the System Specification. This requirement defines Levels 1, 2, and 3.

3.2.3.3.1 Longitudinal Control Force and Travel in Takeoff. With the trim setting optional but fixed, the elevator control forces required during all types of takeoffs defined in the System Specification shall be within the following limits:

Level 1: 30 pounds pull to 10 pounds push

Level 2: 50 pounds pull to 20 pounds push

The elevator control travel during these takeoffs shall not exceed 75 percent of the total travel, stop-to-stop. Here the term takeoff includes the ground run, rotation, lift-off and the ensuing acceleration to climb speed. Takeoff power shall be maintained until climb speed is reached, with the landing gear and highlift devices retracted in the normal manner at speeds from V_{omin} (TO) to V_{omax} (CL).

3.2.3.4 Longitudinal Control in Landing. The elevator control shall be sufficiently effective in the Landing Flight Phase in ground effect that the geometry limited touchdown attitude or the stall angle of

attack can be maintained with any thrust setting. This requirement shall be met with the airplane trimmed for the minimum operational speed in free air. The requirements above define Levels 1 and 2. For Level 3, it shall be possible to execute safe approaches and landings in the presence of a 15 kt total mean wind, roughness length of 0.15 and associated turbulence levels as defined in paragraph 3.7.2.2.

3.2.3.4.1 Longitudinal Control Forces in Landing. The elevator control forces required to meet the requirements of 3.2.3.4 shall be pull forces and shall not exceed the following:

<u>Level</u>	<u>Maximum Control Force - Pounds</u>
1	30
2	50
3	75

3.2.3.4.2 Landing Control Power. A load factor (n) of 1.2g's shall be available for flare at the minimum operational speed before the stall warning is encountered. The requirement applies for the Landing Flight Phase, with trim set for approach, without ground effects, and with an initial thrust setting required for the approach configuration and air-speed. This requirement applies for Levels 1, 2, and 3.

3.2.3.4.3 Pitch Acceleration. With the aircraft initially trimmed at the minimum operational speed for the Landing Flight Phase, it shall be possible to achieve a 3-degree attitude change within one second due to longitudinal column step input only. This requirement defines the minimum Level 1 capability and shall be demonstrated in the most critical steady sideslip required for engine out or crosswind (3.3.7) and out of ground effects.

3.2.3.5 Longitudinal Control Forces in Dives - Service Flight Envelope. With the airplane trimmed for level flight at speeds throughout the Service Flight Envelope, the elevator control forces in 7.5 degree dives held for at least 20 seconds duration within the Service Flight Envelope shall not exceed 30 pounds push or 15 pounds pull. In similar dives, but with trim optional following the dive entry, it shall be possible with normal piloting techniques to maintain the forces within the limits of 10 pounds push or pull. The forces required for recovery from these dives shall be in accordance with the gradients specified in 3.2.2.2.1 although speed may vary during the pullout. In no case shall the forces be greater than 100 pounds during the pullout.

3.2.3.6 Longitudinal Control Forces in Dives - Permissible Flight Envelopes. With the airplane trimmed for level flight at the maximum service speed but with trim optional in the dive, it shall be possible to maintain the

elevator control force within the limits of 35 pounds push or pull in dives to all attainable speeds within the Permissible Flight Envelope. The force required for recovery from these dives shall not exceed 125 pounds. Trim and deceleration devices, etc., may be used to assist in recovery if no unusual pilot technique is required. This requirement defines Level 3.

3.2.3.7 Longitudinal Control in Sideslips. With the airplane trimmed for 1 "g" load factor, wings level, zero sideslip flight, the elevator control force shall be between 10 pounds push or pull to maintain constant speed in steady sideslips with up to 50 pounds of rudder pedal force in either direction. If a variation of elevator control force with sideslip does exist, increasing pull force shall accompany increasing sideslip, and the magnitude and direction of the force change be similar for right and left sideslips. These requirements define Levels 1 and 2. For Level 3, there shall be no uncontrollable pitching motions associated with the sideslips discussed above.

3.2.4 Pitch Attitude Command. For a pitch attitude command mode, the pitch attitude of the aircraft shall be proportional to a longitudinal column displacement from the pitch control trim position. A push force and forward cockpit control displacement shall be required to decrease pitch attitude, and a pull force and aft cockpit control displacement shall be required to increase the pitch attitude. When the column is displaced in either direction and then released the aircraft shall return to the initially referenced attitude unless the referenced attitude has been changed by a pilot or automatic command. The commanded pitch attitude change versus time shall be smooth, and the required performance defined (i.e., overshoot, time history envelopes, etc.,) by the contractor. The limits on the change in pitch attitude to the pilot stick force shall be defined by the contractor based on prototype flight test results.

3.2.5 ^{Deleted} Airspeed Command and Hold Modes. The commanded airspeed change versus time shall be smooth and the desired performance defined (i.e., overshoots, time history envelopes, etc.) by the contractor. For an airspeed hold mode, the airspeed selected by the pilot shall be the reference. Indicated airspeed shall be maintained within ± 5 knots or ± 2 percent of the referenced airspeed, whichever is greater, excepting gust spikes with a duration less than 2 seconds, in the following atmospheric environment:

Low Altitude - 25 kt total wind using 3.7.1 with a roughness length of 0.15 and a corresponding turbulence as defined in 3.7.2.2.

High Altitude - Use turbulence levels associated with the probability of exceedence of 10^{-2} as defined in Figure 7/6.

Any periodic oscillation within this limit shall have a period of at least 20 seconds.

3.2.6 Pitch Rate Command Mode. For a pitch rate command mode, the pitch rate of the aircraft shall be proportional to a longitudinal column displacement from the pitch control trim position. A push force and forward cockpit control displacement shall be required for an airplane nose-down pitch rate, and a pull force and aft cockpit control displacement shall be required for an airplane nose-up pitch rate. The commanded pitch rate time history shall be smooth, and the required performance defined (i.e., overshoot, time history envelopes, etc.) by the contractor. The limits on the change in pitch rate to the pilot stick force shall be defined by the contractor based on prototype flight test results.

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5.12
3.2.7 Pitch Hold Mode. In those airplane states that include attitude hold modes, the airplane shall maintain referenced pitch attitudes throughout the Operational Flight Envelope in the presence of longitudinal trim changes associated with thrust changes, secondary control system operation, normal configuration changes, during lateral-directional maneuvers normally required for mission accomplishment, and in the following atmospheric environment:

Low Altitude - 25kt total wind using 3.7.1 with a roughness length of 0.15 and a corresponding turbulence as defined in paragraph 3.7.2.2.

High Altitude - Use turbulence levels associated with a probability of exceedence of 10^{-2} as defined in Figure 7/6.

Specifically, attitudes shall be maintained in smooth air with static accuracy of ± 0.5 degree in pitch attitude (with wings level) with respect to the reference. RMS attitude deviations shall not exceed 2 degrees in pitch turbulence at the intensities specified. Accuracy requirements shall be achieved and maintained within 3 seconds for either a 5 degree attitude or a 0.5 "g" load factor disturbance, whichever is less, caused by a gust input.

3.3 Lateral-Directional Flying Qualities.

3.3.1 Lateral-Directional Mode Characteristics. The overall lateral-directional damping and frequency requirements for all the system modes (except roll subsidence and structural modes) are shown on Figure 5. The lateral-directional characteristics shall not prevent the pilot from performing accurate touchdowns relative to a 60 foot wide runway.

3.3.1.1 Lateral-Directional Oscillations (Dutch Roll). The frequency, ω_{nd} , and damping ratio, ζ_d , of the lateral directional oscillations -

following a rudder disturbance input shall exceed the minimums in Table V. These minimums are also shown in Figure 5. The requirements shall be met in oscillations of any magnitude that might be experienced in operational use. If the oscillation is nonlinear with amplitude, the requirement shall apply to each cycle of the oscillation. With the control surfaces fixed, ω_{nd} shall always be greater than zero.

TABLE V. Minimum Dutch Roll Frequency and Damping

Level	Flight Phase Category	Min ζ_d^*	Min $\zeta_d \omega_{nd}^*$ rad/sec.	Min ω_{nd} rad/sec.
1	A	0.20	0.35	0.8
	B & C	0.20	0.16	0.8
2	A, B, & C	0.08	0.05	0.5
3	A, B, & C	0.02		0.4

* The governing damping requirement is that yielding the larger value of ζ_d .

3.3.1.2 Roll Mode. The roll-mode time constant, τ_R , shall be no greater than the appropriate value in Table VI.

TABLE VI. Maximum Roll-Mode Time Constant

Flight Phase Category	Level		
	1	2	3
ALL	1.4	3.0	6.0

3.3.1.3 Spiral Stability. The combined effects of spiral stability, flight control system characteristics, and rolling moment change with speed shall be such that following a disturbance in bank of up to 20 degrees, the time for the bank angle to double will be greater than the values in Table VII, and also shown on Figure 5. This requirement shall be met with the airplane trimmed for wings-level, zero-yaw-rate flight with the cockpit controls free.

TABLE VII. Spiral Stability - Minimum Time to Double Amplitude

Flight Phase Category	Level 1	Level 2	Level 3
ALL	20 sec	12 sec	4 sec

3.3.1.4 Coupled Roll-Spiral Oscillation. A coupled roll-spiral mode shall comply with Figure 5.

3.3.2 Lateral-Directional Dynamic Response Characteristics. Lateral-directional dynamic response characteristics are stated in terms of allowable roll rate and bank oscillations, sideslip excursions, roll stick or wheel forces, and rudder pedal forces that occur during specified rolling and turning maneuvers. The requirements of 3.3.2.2, 3.3.2.3, and 3.3.2.4 apply for all roll control commands up to the magnitude required to meet the roll performance of 3.3.4.

3.3.2.1 Lateral-Directional Response to Atmospheric Disturbances. Although no numerical requirements are specified, the airplane shall have acceptable response and controllability characteristics in atmospheric disturbances. The roll acceleration, rate, and displacement responses to side gusts shall be investigated for airplanes with large rolling moment due to sideslip.

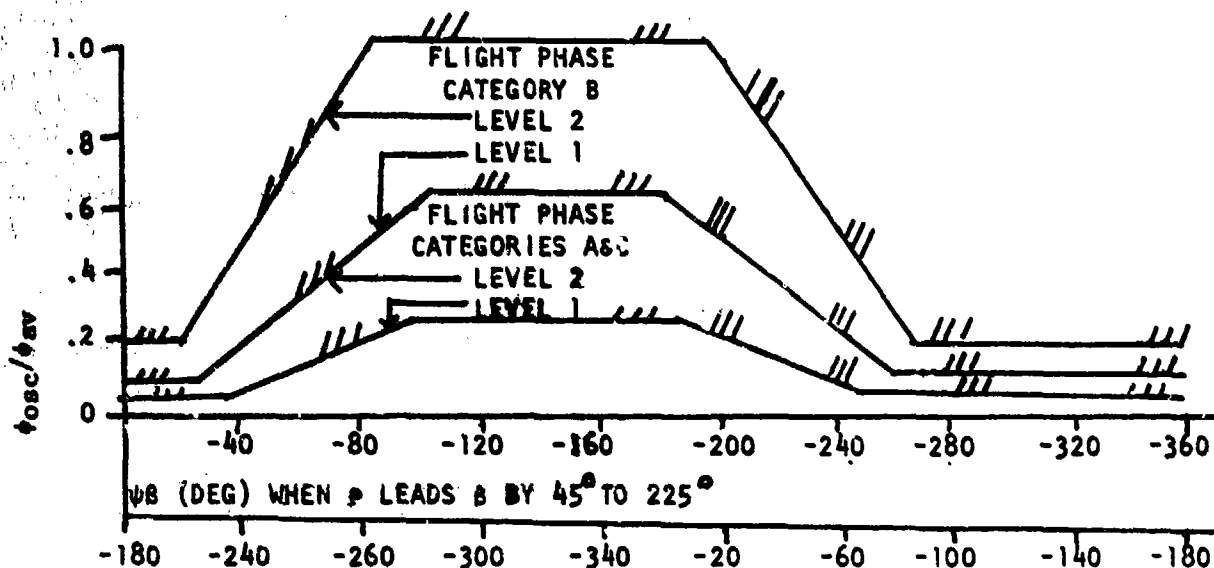
3.3.2.2 Roll Rate Oscillations. Following a rudder pedals free, large step roll control command, the roll rate at the first minimum following the first peak shall be of the same sign and not less than the following percentage of the roll rate at the first peak:

Level	Flight Phase Category	Percent
1	A&B	70
	C	60
2	A&B	60
	C	25
3	ALL	10

For all Levels, the change in bank angle shall always be in the direction of the roll control command. The roll command shall be held fixed until the bank angle has changed at least 90 degrees (i.e., -45° to 45°).

3.3.2.2.1 Not required.

3.3.2.3 Bank Angle Oscillations. The value of the parameter ϕ_{osc}/ϕ_{av} following a large rudder pedals free, large impulse roll control command, shall be within the limits in Figure 6 for Levels 1 and 2. The impulse shall be as abrupt as practical within the strength limits of the pilot and the rate limits of the roll control system.



ψ_B (DEG) WHEN P LEADS β BY 45° TO 225°

ψ_B (DEG) WHEN P LEADS β BY 225° THROUGH 360° TO 45°

FIGURE 6. Bank Angle Oscillation Limitations

3.3.2.4 Sideslip Excursions. Following a rudder pedals free, large step roll control command, the ratio of the sideslip increment, $\Delta\beta$, to the parameter k (6.2.6) shall be less than the values specified herein. The roll command shall be held fixed until the bank angle has changed at least 90 degrees (i.e., -45° to 45°).

Level	Flight Phase Category	Adverse Sideslip	Proverse Sideslip
		(Right roll command causes right sideslip)	(Right roll command causes left sideslip)
1	A	6 degrees	2 degrees
	B&C	10 degrees	3 degrees
2	ALL	15 degrees	4 degrees

3.3.2.5 Control of Sideslip in Rolls. In the rolling maneuvers described in 3.3.4, but with the rudder pedals used for coordination, directional control effectiveness shall be adequate to maintain zero sideslip with a rudder pedal force not greater than 75 pounds. This requirement applies for all Levels.

3.3.2.5.1 Lateral Acceleration Limits, Rolling. For Level 1, the body axis lateral acceleration at the center of gravity shall not exceed a limit defined by a linear variation between $\pm 0.1g$ at zero roll rate and $\pm 0.55g$ at 60 deg/sec, and $\pm 0.55g$ for roll rates greater than 60 deg/sec. These limits shall be satisfied for aircraft in essentially constant altitude flight while rolling smoothly from one side to the other with rudder pedals used for coordination. FC Spec

3.3.2.6 Turn Coordination. For Level 1, the sideslip angle shall not be greater than 2 degrees and lateral acceleration shall not exceed $0.03g$, during steady coordinated turns in either direction using 45 degrees of bank. Rudder pedal force shall not exceed 40 pounds. It shall be possible to perform steady turns at the same bank angles with rudder pedals free, with a roll stick force not exceeding 5 pounds or a roll wheel force not exceeding 10 pounds. The force requirements constitute Levels 1 and 2 with the airplane trimmed for wings-level constant flight path and heading angle flight. FC Spec

3.3.2.7 Residual Oscillations. Any sustained residual oscillations shall not interfere with the pilot's ability to perform the tasks required in the service use of the airplane. For Level 1, oscillations in lateral acceleration at the pilot's station greater than $\pm 0.01g$ will be considered excessive for any Flight Phase.

3.3.3 Pilot-Induced Oscillations. There shall be no tendency for sustained or uncontrollable lateral-directional oscillations resulting from efforts of the pilot to control the airplane. This requirement applies for all Levels.

3.3.4 Roll Control Effectiveness. Roll performance in terms of bank angle change in a given time, ϕ_r , is specified in Table VIII. Roll control commands shall be initiated from zero roll rate in the form of abrupt inputs, with time measured from the initiation of control force application. Rudder pedals may be used to reduce sideslip that retards roll rate (not to produce sideslip that augments roll rate) if rudder pedal inputs are simple, easily coordinated with roll control inputs, and consistent with piloting techniques. Roll control with all systems operating normally shall be sufficiently effective to balance the airplane in roll throughout the Service Flight Envelope in turbulence levels associated with a probability of exceedance of 10^{-5} as defined in Figure 7/6. The Category C, Level 3, roll requirement shall be met with a maximum crosswind magnitude as specified in 3.3.7.

TABLE VIII. Maximum Time to Achieve 30° Bank Angle †

Flight Phase Category	Time (sec)		
	Level 1	Level 2	Level 3
A & B*	2.0	3.0	4.0
C	2.5	3.2	4.0

* For Aerial Delivery at 1.2 V_g , Category C requirements apply.

† For takeoff, the required bank angle can be reduced proportional to the ratio of the maximum rolling moment of inertia for the maximum authorized landing weight to the rolling moment of inertia at takeoff, but the Level 1 requirement shall not be reduced below the listed value for Level 3.

3.3.4.1 Deleted.

3.3.4.2 Roll Control Forces. The stick or wheel force required to obtain the rolling performance specified in 3.3.4 shall be neither greater than the maximum in Table IX nor less than the breakout force plus:

- Level 1 -- one-fourth the values in Table IX
- Level 2 -- one-eighth the values in Table IX
- Level 3 -- zero

TABLE IX. Maximum Roll Control Force

Level	Maximum Force (lb)
1	25
2	30
3	35

The control forces are measured tangential to the arc described by the pilot's index finger.

3.3.4.3 Linearity of Roll Response. There shall be no objectionable nonlinearities in the variation of roll rate for a rate command system and of roll attitude for an attitude command system with roll control deflection or force. This is considered a Level 1 and 2 requirement.

3.3.4.4 Wheel Control Throw. For airplanes with wheel controllers, the wheel throw necessary to meet the roll performance requirements specified in 3.3.4 shall not exceed 70 degrees in either direction. With all lateral augmentation off, the requirement may be relaxed to 80 degrees. This requirement applies to all Levels.

3.3.4.5 Deleted.

3.3.5 Directional Control Characteristics. Directional control characteristics shall enable the pilot to balance yawing moments and control yaw and sideslip. Specifically, compliance with 3.3.5.1 through 3.3.5.5 shall be demonstrated.

3.3.5.1 Directional Control with Speed Change. When initially trimmed directionally with symmetric power, the trim change with speed shall be such that constant flight path and heading angle can be maintained over a speed range of ± 30 percent of the trim speed or ± 100 knots equivalent airspeed, whichever is less (except where limited by boundaries of the Service Flight Envelope). Rudder pedal forces shall not be greater than 40 pounds for Levels 1 and 2 nor 120 pounds for Level 3 without retrimming.

3.3.5.1.1 Directional Control with Asymmetric Loading. Not applicable.

3.3.5.2 Directional Control in Go-Around. The response to thrust, configuration, and airspeed changes shall be such that the pilot can maintain constant heading angle during go arounds initiated at speeds down to V_S (PA), with rudder pedal forces not exceeding 40 pounds when trimmed at V_{min} (PA). The preceding requirements apply for Levels 1 and 2. The Level 3 requirement is to maintain a constant heading angle for these conditions with rudder pedal forces not exceeding 120 pounds. For all Levels, bank angles up to 5 degrees are permitted. Further, consistent satisfactory go around performance shall be attained with a reasonable pilot workload.

3.3.5.3 Yaw Control. Within the Operational Flight Envelope for the Landing Flight Phase, the yaw attitude change in 2 seconds for an abrupt step displacement of the yaw control shall be between 5 and 10 degrees for Level 1. This requirement applies with the aircraft trimmed for symmetrical flight and with the wings held level during the maneuver.

3.3.5.4 Yaw Control Linearity and Sensitivity. There shall be no objectionable nonlinearities in the variation of directional response with yaw control deflection or forces. There shall be no excessive sensitivity or sluggishness of airplane yaw response due to rudder pedal deflection or force that would prevent such things as satisfactory turn coordination, decrab for touchdown in crosswind, or control of engine failure transients.

3.3.5.5 Heading Control. Within the Operational Flight Envelope for Category C the heading delay, τ_ψ , shall be less than the values shown below:

Level	τ_ψ , sec
1	1.2
2	2.0
3	3.0

The aircraft shall be initially trimmed when the maneuver is begun. An explanation of τ_ψ is presented in 6.2.6.

3.3.6 Lateral-Directional Characteristics in Steady Sideslips. The requirements of 3.3.6.1 through 3.3.6.3.1 concern rudder pedal induced, unaccelerated, zero yaw rate sideslips with the airplane trimmed for wings level, constant flight path and heading angle. Paragraphs 3.3.6.1 through 3.3.6.3 apply at sideslip angles up to those produced by full rudder pedal deflections.

3.3.6.1 Yawing Moments in Steady Sideslips. For the sideslips specified in 3.3.6, right rudder pedal deflection and force shall produce left sideslips and left rudder pedal deflection and force shall produce right sideslips. For Levels 1 and 2 the following requirements shall apply. The variation of sideslip angle with rudder pedal deflection shall be linear for sideslip angles between +15 degrees and -15 degrees. For larger sideslip angles, an increase in rudder pedal deflection shall always be required for an increase in sideslip. The variation of sideslip angle with rudder pedal force shall be linear for sideslip angles between +10 degrees and -10 degrees. Although a lightening of rudder pedal force is acceptable for sideslip angles outside this range, the rudder pedal force shall never reduce to zero.

3.3.6.2 Side Forces in Steady Sideslips. For the sideslips of 3.3.6, an increase in right bank angle shall accompany an increase in right sideslip, and an increase in left bank angle shall accompany an increase in left sideslip. This requirement applies for all Levels.

3.3.6.3 Rolling Moments in Steady Sideslips. For the sideslips of 3.3.6, left or zero roll control deflection and force shall accompany

left sideslips, and right or zero roll control deflection and force shall accompany right sideslips. For Levels 1 and 2, the variation of roll control deflection and force with sideslip angle shall be linear.

3.3.6.3.1 Exception for Go-Around. The requirement of 3.3.6.3 may be excepted for go around if task performance is not impaired, and no more than 50 percent of roll control power available to the pilot and no more than 10 pounds of roll control force are required in a direction opposite to that specified in 3.3.6.3.

3.3.6.3.2 Positive Effective Dihedral Limit. The positive effective dihedral (right roll control for right sideslip and left roll control for left sideslip) shall never be so great that the Level 3 roll requirements cannot be met, and no more than 10 pounds of roll control force shall be required for sideslip angles of 3.3.6.

3.3.7 Lateral-Directional Control in Crosswinds. It shall be possible to takeoff and land with normal pilot skill and technique in crosswinds 90 degrees to the runway with velocities up to those specified in Table X. Level of flying quality in zero crosswind shall be maintained for crosswinds up to the magnitudes shown in Table X, although the pilot workload may increase. Roll control forces shall not exceed 10 pounds for Level 1 or 20 pounds for Levels 2 and 3. Rudder pedal forces shall not exceed 100 pounds for Level 1, 140 pounds for Level 2, and 180 pounds for Level 3.

TABLE X. Crosswind Velocity

Level	Crosswind at 50 Ft Altitude
1 & 2	30 knots
3	15 knots

3.3.7.1 Final Approach in Crosswinds. Deleted.

3.3.7.2 Takeoff Run and Landing Rollout in Crosswinds. Rudder and roll control power, in conjunction with other normal means of control, shall be adequate to maintain a straight path on the ground or other landing surface. This requirement applies in calm air and in crosswinds up to the values specified in Table X with cockpit control forces not exceeding the values specified in 3.3.7.

3.3.7.2.1 Cold and Wet Weather Operation. The requirements of 3.3.7 2 apply on wet runways and on snow packed and icy runways. If compliance is not demonstrated under these adverse runway conditions for Level 1, directional control shall be maintained by use of aerodynamic controls alone at all airspeeds above 30 knots. For very slippery runways, the requirement need not apply for crosswind components at which the force tending to blow the airplane off the runway exceeds the opposing tire runway frictional force with the tires supporting all of the weight of the airplane.

3.3.7.3 Taxiing Wind Speed Limits. It shall be possible to taxi at any angle to a 45 knot wind for Level 1.

3.3.8 Lateral-Directional Control in Dives with Symmetric Thrust. Rudder and roll control power shall be adequate to maintain wings level and zero sideslip, without retrimming, throughout the dives and pullouts of 3.2.3.5 and 3.2.3.6, for all Levels. In the Service Flight Envelope, roll control forces shall not exceed 10 pounds. Rudder pedal forces shall not exceed 50 pounds.

3.3.9 Lateral-Directional Control with Asymmetric Thrust. Following sudden asymmetric loss of thrust from any factor, the airplane shall be safely controllable. The requirements of 3.3.9.1 through 3.3.9.4 apply for the appropriate Flight Phases when any single failure or malfunction causes loss of thrust on one or more engines. The effect of the failure or malfunction on all subsystems powered or driven by the failed propulsive system shall also be included. Systems not affected by the thrust loss are assumed to be working normally.

3.3.9.1 Thrust Loss During Takeoff Run. It shall be possible for the pilot to maintain control of an airplane on the takeoff surface following sudden loss of thrust from the most critical factor. Thereafter, it shall be possible to achieve and maintain a straight path on a concrete (hard) takeoff surface without a deviation of more than 30 feet from the path originally intended, with rudder pedal forces not exceeding 120 pounds. For the Tactical Mobility Mission runway defined in paragraph 3.2.1.1 of the System Specification, deviation from the path originally intended shall not result in the main landing gear tires extending beyond the runway edge, nor the rudder pedal forces to exceed 120 pounds. The deviations from the intended path shall be analyzed for a sudden fuel cut-off to the critical engine, with a 1 second time delay between the time of the engine failure and the start of the pilot control input. Flight test results shall be used to demonstrate that the deviations from the path intended are less than required above. The deviations measured from flight test shall include a pilot delay time determined by adding the largest flight test delay time plus an additional 0.2 seconds to account for normal pilot surprise.

For the continued takeoff the allowable deviations shall not be exceeded when thrust is lost from the refusal speed (based on the shortest runway defined in the System Specification) to the maximum takeoff speed, with takeoff thrust maintained on the operative engine(s), using only pitch, roll and yaw controls. No forward movement or pressure shall be applied to the control column. For the aborted takeoff, the allowable deviations shall not be exceeded at all speeds below the maximum takeoff speed. However, additional controls such as nosewheel steering and differential braking may be used. Automatic devices which normally operate in the event of a thrust failure may be used in either case.

3.3.9.2 Thrust Loss After Takeoff. For takeoff it shall be possible without a manually commanded configuration change to achieve constant flight path and heading angle following sudden asymmetric loss of thrust at Service Flight Envelope speeds from $V_{min}(TO)$ to $V_{max}(TO)$. Thereafter it shall be possible to maintain constant flight path and heading angle throughout the climb out. The rudder pedal force shall not exceed 120 pounds. Roll control force shall not exceed the Level 3 force limits specified in 3.3.4.2. The Category C, Level 3, roll requirement of 3.3.4 shall be met with takeoff thrust maintained on the operative engine(s) and trim at normal settings for takeoff with symmetric thrust. Automatic devices which normally operate in the event of a thrust failure may be used, and the airplane may be banked up to 5 degrees in the direction to assist control.

3.3.9.3 Transient Effects. The airplane motions following sudden asymmetric loss of thrust shall be such that dangerous conditions can be avoided by pilot corrective action. A realistic time delay (3.4.9) of at least 1 second shall be considered.

3.3.9.4 Asymmetric Thrust - Rudder Pedals Free. The static directional stability shall be such that all speeds above $1.4 V_{min}$, with asymmetric loss of thrust and with normal rated thrust on the other engine(s), the airplane with rudder pedals free can be balanced directionally in unaccelerated, constant flight path and heading angle flight. The trim settings shall be those required for wings level, constant flight path and heading angle flight prior to the failure. Roll control forces shall not exceed the Level 2 upper limits specified in 3.3.4.2 for Levels 1 and 2, and shall not exceed the Level 3 upper limits for Level 3.

3.3.9.5 Two Engines Inoperative. For aircraft with more than two engines, with any engine initially failed, it shall be possible upon failure of the most critical remaining engine to stop transient motion at the one engine out speed for maximum range, and thereafter to maintain straight flight from that speed to the speed for maximum range with two engines failed. In addition, the transient motions following

a sudden simultaneous failure of two engines at any speed above V_{omin} (CL) shall comply with 3.3.9.3.

3.3.10' Roll Attitude Command. For a roll attitude command mode, the roll attitude of the aircraft shall be proportional to a fixed roll control displacement from the roll control trim position. Right roll control displacement and force shall cause a positive increase in bank angle, and a left roll control displacement and force shall cause a decrease in positive bank angle. When the roll control is displaced in either direction and then released, the aircraft shall return to the initially referenced roll attitude. The commanded roll attitude change versus time shall be smooth, and the desired performance (i.e., overshoot, time history envelopes, etc.) defined by the contractor. The limits on the change in roll attitude to the pilot's roll control force shall be defined by the contractor based on prototype flight test results.

3.3.11 Roll Rate Command Mode. For a roll rate command mode, the roll rate of the airplane shall be proportional to a fixed roll control displacement from the roll control trim position. Right roll control displacement and force shall cause a right wing down roll rate, and a left roll control displacement and force shall cause a left wing down roll rate. The commanded roll rate time history shall be smooth, and the desired performance (i.e., overshoot, time history envelopes, etc.) defined by the contractor. The limits on the commanded roll rate to the pilot roll control force shall be defined by the contractor based on prototype flight test results.

3.3.12 Roll Attitude Hold Mode. For a roll attitude hold mode, the referenced roll attitude shall be maintained in smooth air with a static accuracy of ± 1.0 degree. RMS attitude deviations shall not exceed 10 degrees in roll attitude in the following atmospheric environment:

Low Altitude - 25 kt total wind using 3.7.1 with a roughness length of 0.15 and corresponding turbulence as defined in paragraph 3.7.2.2.

High Altitude - Use turbulence levels associated with a probability of exceedence of 10^{-2} as defined in Figure 7/6.

Accuracy requirements shall be achieved and maintained within 3 seconds for a 5 degree attitude disturbance due to gust.

3.4 Miscellaneous Flying Qualities.

3.4.1 Dangerous Flight Conditions. Dangerous conditions may exist where the airplane should not be flown. When approaching these flight conditions, it shall be possible by clearly discernible means for the pilot to recognize the impending dangers and take preventive action.

3.4.1.1 Warning and Indication. Warning or indication of approach to a dangerous condition shall be clear and unambiguous. If a warning or indication device is required, functional failure of the device shall be indicated to the pilot.

3.4.1.2 Devices for Indication, Warning, Prevention, Recovery. It is intended that dangerous flight conditions be eliminated and the requirements of this specification met by appropriate aerodynamic design and mass distribution, rather than through incorporation of a special device or devices. As a minimum, these devices shall perform their function whenever needed, but shall not limit flight within the Operational Flight Envelope. Neither normal nor inadvertent operation of such devices shall create a hazard to the airplane. For Levels 1 and 2, nuisance operation shall not be possible. Functional failure of the devices shall be indicated to the pilot.

3.4.2 Flight at High Angle of Attack. The requirements of 3.4.2 through 3.4.2.2.2 concern stall warning, stalls, departure from controlled flight, post-stall gyrations, spins, recoveries and related characteristics. They apply at speeds and angles of attack which in general are outside the Service Flight Envelope. They are intended to assure safety and the absence of mission limitations due to high angle of attack characteristics.

3.4.2.1 Stalls. Stall usually is a phenomenon caused by airflow separation induced by high angle of attack, and for the C-1XA, a reduction in thrust; it may also be defined by some limit on usable angle of attack (3.1.9.2). The stall requirements apply for all Airplane Normal States in straight unaccelerated flight and in turns and pull-ups with attainable normal acceleration up to n_L . The pilot shall be warned when Failure States (other than Special Failure States) exist that affect stall characteristics. The pilot shall be able to safely terminate or complete the flight phase that was in progress at the time of the failure.

3.4.2.1.1 Stall Approach. The stall approach shall be accompanied by an easily perceptible warning. Acceptable stall warning for

unaccelerated and accelerated stalls consists of shaking of the cockpit controls, buffeting or shaking of the airplane, or a combination of both. The onset of this warning shall occur within the ranges specified in 3.4.2.1.1.1, but not within the Operational Flight Envelope. The warning shall continue until the angle of attack is reduced to a value less than that for warning onset. At all angles of attack up to the stall, the cockpit controls shall remain effective in their normal sense, and small control inputs shall not result in departure from controlled flight. Prior to the stall, uncommanded oscillations shall not be objectionable to the pilot.

3.4.2.1.1.1 Warning Speed for Stalls at 1g Normal to the Flight Path. Warning onset for stalls (3.1.9.2) at 1g normal to the flight path, shall occur between the following limits when the stall is approached gradually.

<u>Flight Phase</u>	<u>Minimum Speed For Onset</u>	<u>Maximum Speed for Onset</u>
Approach	Higher of $1.05V_S$ or $V_S + 5$ knots	Higher of $1.10V_S$ or $V_S + 10$ knots
All Other	Higher of $1.05V_S$ or $V_S + 5$ knots	Higher of $1.15 V_S$ or $V_S + 15$ knots

3.4.2.1.2 Stall Characteristics. In the unaccelerated stalls of 3.4.2.1 the airplane shall not exhibit rolling, yawing, or pitching at the stall which cannot be controlled to stay within 20 degrees. It is desired that no pitch-up tendencies occur in unaccelerated or accelerated stalls. In unaccelerated stalls, mild nose-up pitch motion may be acceptable if no dangerous, unrecoverable, or objectionable flight conditions result. A mild nose-up tendency may be acceptable in accelerated stalls if the operational effectiveness of the airplane is not compromised and:

- a. The airplane has adequate stall warning
- b. Pitch surface effectiveness is such that it is possible to stop the pitch-up motion promptly and reduce the angle of attack, and
- c. At no point during the stall, stall approach, or recovery does any portion of the airplane exceed structural limit loads.

These requirements apply for all stalls, including stalls entered abruptly.

3.4.2.1.3 Stall Prevention and Recovery. It shall be possible to prevent the stall by moderate use of the pitch or throttle control at the onset of the stall warning. It shall be possible to recover from a stall by simple use of the pitch, roll, and yaw controls with cockpit

control forces not to exceed those of 3.4.5.1, and to regain level flight without excessive loss of altitude or buildup of speed. Throttles may be changed to aid stall recovery. In the straight flight stalls of 3.4.2.1, with the airplane trimmed at an airspeed not greater than $1.4 V_S$, and with a speed reduction rate of at least 4.0 knots-per second, the pitch control power shall be sufficient to recover from any attainable angle of attack.

3.4.2.1.3.1 One-Engine-Out Stalls. It shall be possible to recover safely from stalls with the critical engine inoperative.

3.4.2.2 Post-Stall Gyration and Spin. The post-stall gyration and spin requirements apply to all modes of motion that can be entered from upsets, decelerations, and extreme maneuvers appropriate to the Flight Phase Category. Entry angle of attack and sideslip up to maximum control capability and under dynamic flight conditions are to be included, except as limited by structural considerations. For all Flight Phase Categories, thrust settings up to and including takeoff thrust shall be included, with and without one critical engine inoperative at entry. The requirements hold for all Airplane Normal States and for all states of stability and control augmentation systems, except approved by Special Failure States. Automatic disengagement of augmentation systems is permissible if it is necessary and does not prevent meeting any other requirements; reengagement shall be possible in flight following recovery.

3.4.2.2.1 Departure From Controlled Flight. The airplane shall be extremely resistant to post-stall gyrations, spins, and departure from controlled flight. The airplane shall exhibit no uncommanded motion which cannot be arrested promptly by simple applications of pilot control.

3.4.2.2.2 Recovery From Post-Stall Gyration and Spins. The airplane must be readily recoverable from all attainable attitudes and motions. The post-stall characteristics shall be determined.

3.4.3 Spin Recovery. Deleted.

3.4.4 Roll-Pitch-Yaw Coupling. During tactical maneuvers involving rolls through angles of up to 120 degrees, the yawing and pitching shall not be so severe as to impair the tactical effectiveness of the maneuver. These requirements define Level 1 and Level 2 operation.

3.4.5 Control Harmony. The pitch and roll force and control displacement sensitivities and breakout forces shall be compatible so that intentional inputs to one control axis will not cause inadvertent inputs to the other.

3.4.5.1 Control Force Coordination. The cockpit control forces required to perform maneuvers which are normal for the airplane should have magnitudes which are related to the pilot's capability to produce such forces in combination. The following control force levels are considered to be limiting values compatible with the pilot's capability to apply simultaneous forces:

<u>Pitch</u>	<u>Roll</u>	<u>Yaw</u>
50 pounds	25 pounds	175 pounds

3.4.6 Buffet. Within the boundaries of the Operational Flight Envelope, there shall be no objectionable buffet which might detract from the effectiveness of the airplane in executing its intended missions.

3.4.7 Release of Stores. The intentional release of any stores or internal cargo shall not result in objectionable flight characteristics for Levels 1 and 2. Further, the intentional release of stores or internal cargo shall never result in dangerous or intolerable flight characteristics. This requirement applies for all flight conditions and store loadings at which normal or emergency store release is structurally permissible.

3.4.8 Effects of Armament Delivery and Special Equipment. Operation of moveable parts such as cargo doors, refueling devices, and delivery or pickup of cargo shall not cause buffet, trim changes, or other characteristics which impair the tactical effectiveness of the airplane under any pertinent flight condition. These requirements shall be met for Levels 1 and 2.

3.4.9 Transients Following Failures. The airplane motions following sudden airplane system or component failures shall be such that dangerous conditions can be avoided by pilot corrective action. A realistic time delay of at least one second between the failure and initiation of pilot corrective action shall be incorporated when determining compliance. This time delay should include an interval between the occurrence of the failure and the occurrence of a cue such as acceleration, rate, displacement, or sound that will definitely indicate to the pilot that a failure has occurred, plus an additional interval which represents the time required for the pilot to diagnose the situation and initiate corrective action.

3.4.10 Failures. No single failure of any component or system shall result in dangerous or intolerable flying qualities; Special Failure

States (3.1.6.2.1) are excepted. The crew member concerned shall be provided with immediate and easily interpreted indications whenever failures occur that require or limit any flight crew action or decision.

3.5 Characteristics of the Manual Flight Control System (MFCS).

3.5.1 General Characteristics. Manual Flight Control Systems consist of electrical, mechanical and hydraulic components which transmit pilot control commands or generate and convey commands which augment pilot control commands, and thereby accomplish flight control functions. This classification includes the longitudinal, lateral-directional, lift and drag control systems. In addition, their associated augmentation, performance limiting and control devices are included. Thrust control shall also be included in this definition if thrust is used by the pilot to control the flight path of the aircraft. The requirements of this section are concerned with those aspects of the Manual Flight Control System which are directly related to flying qualities.

3.5.2 Mechanical Characteristics. Some of the important characteristics of control systems are friction preload, lost motion, flexibility, mass imbalance and inertia, nonlinear gearing and rate limiting. Requirements for some of these characteristics are contained in 3.5.2.1 through 3.5.2.4.

3.5.2.1 Control Centering and Breakout Forces. Longitudinal, lateral, and directional controls should exhibit positive centering in flight at any normal trim setting. Although absolute centering is not required, the combined effects of centering, breakout force, stability and force gradient shall not produce objectionable flight characteristics, such as poor precision tracking ability, or permit large departures from trim conditions with controls free. Breakout forces, including friction, preload, etc., shall be within the limits of Table XI. The values in Table XI refer to the cockpit control force required to start movement of the control surface in flight.

TABLE XI. Allowable Breakout For cs, Pounds

LEVEL	MINIMUM-MAXIMUM BREAKOUT FORCE - LB			
	Pitch	Column	Rudder Pedals	Wheel
1	1.0 to 5.0		5.0 to 8.0	0.5 to 4.0
2	0.5 to 7.0		2.0 to 14.0	0.5 to 7.0
3	0 to 10.0		0 to 28.0	0 to 10.0

Measurement of breakout force on the ground will ordinarily suffice in lieu of actual flight measurement, provided that qualitative agreement between ground measurement and flight observation can be established.

3.5.2.2 Cockpit Control Free Play. Any motion of the cockpit control which does not move the control surface in flight (free play) shall not result in objectionable flight characteristics, particularly for small amplitude control inputs.

3.5.2.3 Rate of Control Displacement. The ability of the airplane to perform the operational maneuvers required of it shall not be limited in the atmospheric environment specified in 3.7 by control surface deflection rates. Adequate control of the airplane shall be maintained in the following environment:

Low Altitude - 25kt total wind using 3.7.1 with a roughness length of 0.15 and corresponding turbulence as defined in paragraph 3.7.2.2.

High Altitude - Use turbulence levels associated with a probability of exceedence of 10^{-5} as defined in Figure 7/6.

The effect of engine speed and the duty cycle of the Manual Flight Control System together with the pilot control techniques shall be included when establishing compliance with this requirement.

3.5.2.4 Adjustable Controls. When a cockpit control is adjustable for pilot physical dimensions or comfort, the control forces defined in 6.2 refer to the mean adjustment. A force referred to any other adjustment shall not differ by more than 10 percent from the force referred to the mean adjustment.

3.5.3 Dynamic Characteristics. The response of the control surfaces in flight shall not lag the cockpit control force inputs by more than the angles shown in Table XII for frequencies equal to or less than the frequencies shown in Table XII.

TABLE XII. Allowable Control Surface Lags

Level	Allowable Lag - deg		Control	Upper Frequency - rad/sec
	Category A and C Flight Phases	Category B Flight Phases	Pitch	ω_{sp} or 2 (whichever is larger)
1 and 2	30	45	rudder & roll	ω_d or $\frac{1}{T_R}$ (whichever is larger)
3	60			

The lags referred to are the phase angles obtained from steady state frequency responses, for reasonably large amplitude force inputs. The lags for very small control force amplitudes shall be small enough that they do not interfere with the pilot's ability to perform any precision tasks required in normal operation.

3.5.3.1 Control Feel. In flight, the cockpit control deflection shall not lead the cockpit control force for any frequency or force amplitude. This requirement applies to the pitch, roll and yaw controls. In flight, the cockpit control deflection shall not lag the cockpit control force by more than the angles listed in 3.5.3, for frequencies equal to or less than those listed in 3.5.3, for reasonably large force inputs. The lags for very small control force amplitudes shall not interfere with the pilot's ability to perform precision tasks required in normal operation.

3.5.3.2 Damping. All control system oscillations shall be well damped (see paragraph 3.2.2.1.2) unless they are of such an amplitude, frequency, and phasing that they do not result in objectionable oscillations of the cockpit controls or the airframe during abrupt maneuvers and during flight in atmospheric environments up to the following:

Low Altitude - 25kt total wind using 3.7.1 with a roughness length of 0.15 and corresponding turbulence as defined in paragraph 3.7.2.2.

High Altitude - Use turbulence levels associated with a probability of exceedance of 10^{-5} as defined in Figure 7/6.

3.5.4 Augmentation Systems. Normal operation of stability augmentation and control augmentation systems and devices shall not introduce any objectionable flight or ground handling characteristics.

3.5.4.1 Performance of Augmentation Systems. Performance degradation of augmentation systems caused by atmospheric disturbances and by structural vibrations shall be considered.

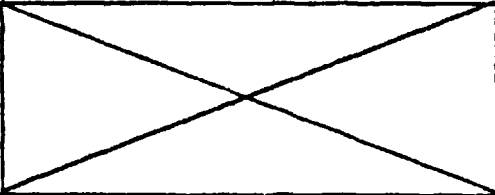
3.5.4.2 Saturation of Augmentation Systems. Limits on the authority of augmentation systems or saturation of equipment shall not result in objectionable flying qualities. In particular, this requirement shall be met during rapid large amplitude maneuvers, during operation near V_S , and during flight in the atmospheric environment of paragraph 3.7. Saturation shall not degrade control below an adequate level for the following atmospheric environment:

Low Altitude - 25 kt total wind using 3.7.1 with a roughness length of 0.15 and corresponding turbulence as defined in paragraph 3.7.2.2.

High Altitude - Use turbulence levels associated with a probability of exceedence of 10^{-5} as defined in Figure 7/5.

FC Spec
3.5.5 Failures. If the flying qualities with any or all of the augmentation devices inoperative or partially inoperative are dangerous or intolerable, provisions shall be incorporated to preclude the occurrence of that set of failures within the probability of encountering less than Level 3 flying qualities establishes in paragraph 3.1.10.2. Failure induced transient motions and trim changes resulting either immediately after failure or upon subsequent transfer to alternate control modes shall be small and gradual enough that dangerous flying qualities are extremely remote.

3.5.5.1 Failure Transients. With controls free, the airplane motions due to failures described in 3.5.5 shall not exceed the following limits for at least 2 seconds following the failure as a function of the Level of flying qualities after the failure transient has subsided:

Level (after failure)	Normal or Lateral Acceleration at Pilot's Station		Roll Rate	
	Categories A&B	Category C	Categories A&B	Category C
1	±0.5g	±0.2g	±10 deg/sec	±4 deg/sec
2	±0.5g	±0.4g	±10 deg/sec	±8 deg/sec
3	Transients due to failures shall not exceed 75 percent of limit normal or lateral load factor.			

3.5.5.2 Trim Changes Due to Failures. The change in control forces required to maintain attitude and sideslip for the failures described in 3.5.5 shall not exceed the following limits for at least 5 seconds following the failure:

Pitch ----- 20 pounds
 Roll ----- 10 pounds
 Yaw ----- 50 pounds

3.5.6 Transfer to Alternate Control Modes. The transient motions and trim changes resulting from the intentional engagement or disengagement of any portion of the Manual Flight Control System by the pilot shall be small and gradual enough that dangerous flying qualities never result.

3.5.6.1 Transients. With controls free, the transients resulting from the situations described in 3.5.6 shall not exceed the following limits for at least 2 seconds following the transfer:

Within the Operational Flight Envelope	$\pm 0.05g$ normal or lateral acceleration at the pilot's station and ± 1 degree per second roll.
Within the Service Flight Envelope	$\pm 0.5g$ normal or lateral acceleration at the pilot's station or ± 5 degrees per second roll.

These requirements apply only for Airplane Normal States.

3.5.6.2 Trim Changes. The change in control forces required to maintain attitude and sideslip for the situations described in 3.5.6 shall not exceed the following limits for at least 5 seconds following the transfer:

Pitch _____	20 pounds
Roll _____	10 pounds
Yaw _____	50 pounds

These requirements apply only for Airplane Normal States.

3.6 Additional Characteristics of the Manual Flight Control System.

3.6.1 Trim System. For constant flight path and heading angle the trimming devices shall be capable of reducing the pitch, roll and yaw control forces to zero for Levels 1 and 2. For Level 3, the untrimmed cockpit control forces shall not exceed 10 pounds for pitch, 5 pounds for roll, and 20 pounds for yaw. The failures to be considered in applying the Level 2 and 3 requirements shall include trim sticking and runaway in either direction. It is permissible to meet the Level 2 and 3 requirements by providing the pilot with alternate trim mechanisms or override capability.

3.6.1.1 Trim for Asymmetric Thrust. For all multiengine airplanes, it shall be possible to trim the pitch, yaw, and roll control forces to zero in constant flight path and heading angle flight with up to

two engines inoperative following asymmetric loss of thrust from the most critical factors (3.3.9). For two engine aircraft, this requirement applies for one engine inoperative. This requirement defines Level 1 in level flight cruise at speeds from the maximum range speed for the engine(s) out configuration to the speed obtainable with normal rated thrust on the functioning engine(s).

3.6.1.2 Rate of Trim Operation. Trim devices shall operate rapidly enough to enable the pilot to maintain low control forces under changing conditions normally encountered in service, yet not so rapidly as to cause oversensitivity or trim precision difficulties under any conditions. Specifically, it shall be possible to trim the pitch control forces to less than ± 10 pounds throughout dives required in normal service operation, and level flight accelerations at takeoff thrust from 250 knots or $V_{R/C}$, whichever is less, to V_{max} at any altitude, when the airplane is trimmed for level flight prior to initiation of the maneuver.

3.6.1.3 Stalling of Trim Systems. Stalling of a trim system due to aerodynamic loads during maneuvers shall not result in an unsafe condition. Specifically, the longitudinal trim system shall be capable of operating during the dive recoveries of 3.2.3.6 at any attainable permissible load factor, at any possible position of the trimming device.

3.6.1.4 Trim System Irreversibility. All trimming devices shall maintain a given setting indefinitely, unless changed by the pilot, or by a special automatic interconnect such as to the landing flaps, or by the operation of an augmentation device. If an automatic interconnect or augmentation device is used in conjunction with a trim device, provision shall be made to ensure the accurate return of the device to its initial trim position on completion of each interconnect or augmentation operation.

3.6.2 Speed and Flight-Path Control Devices. The effectiveness and response times of the fore and aft force controls, in combination with the other longitudinal controls, shall be sufficient to provide adequate control of flight path and airspeed at any flight condition within the Operational Flight Envelope. This requirement may be met by use of devices such as throttles, thrust reversers, auxiliary drag devices, and flaps.

3.6.3 Transients and Trim Changes. The transient and steady state trim changes for normal operation of such items as throttle, flaps, slats, speed brakes, deceleration devices, dive recovery devices and landing gear shall not impose excessive control forces to maintain the desired heading, altitude, attitude, rate of climb, speed or load factor, without use of the trimmer control. This requirement applies

to all in flight configuration changes and combinations of changes made under service conditions, including the effects of asymmetric operations such as unequal operation of landing gear, speed brakes, slats or flaps.

3.6.3.1 Pitch Trim Changes. The pitch trim changes caused by operation of the Manual Flight Control System shall not be so large that a peak pitch control force in excess of 20 pounds is required under conditions representative of operational procedures. Generally, the conditions listed in Table XIII will suffice for determination of compliance with this requirement. With the airplane trimmed for each specific initial condition, the peak force required to maintain the specified parameter constant following the specified configuration change shall not exceed 20 pounds for at least 5 seconds following the completion of the pilot action initiating the configuration change. The magnitude and rate of trim change subsequent to this time period shall be such that the forces are easily trimmed by use of the normal trimming devices. The above requirements define Level 1. For Levels 2 and 3, the allowable forces are increased by 50 percent. If automatic trim devices are selectable by the pilot, they shall be inoperable when showing compliance with this requirement.

3.6.4 Auxiliary Dive Recovery Devices. Operation of any auxiliary device intended solely for dive recovery shall always produce a positive increment of normal acceleration, but the total normal load factor shall never exceed 0.8 n_L with the controls free.

3.3 Delete.

Table XIII. Pitch Trim Change Conditions

	Flight Phase	Initial Trim Conditions					Configuration Change	Parameter to be held constant
		Altitude	Speed	Landing Gear	High-lift Devices	Thrust		
1	Approach	$h_{0\min}$	Normal pattern entry speed	Up	Up	TLF	Gear down	Altitude and airspeed *
2				Up	Up	TLF	Gear down	Altitude
3**				Down	Up	TLF or normal thrust	Extend high lift devices to approach deflection	Normal altitude and airspeed *
4**				Down	Up	TLF or normal thrust	Extend high lift devices to approach deflection	Normal altitude
5			↓	Down	Approach deflection	TLF	Minimum thrust	Airspeed
6***			$V_{C\min}$	Down		TLF or normal thrust	Extend Deceleration Device	Airspeed

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TABLE XIII. Pitch Trim Change Conditions (cont)

	Flight Phase	Initial Trim Conditions					Configuration Change	Parameter to be held constant
		Altitude	Speed	Landing Gear	High-lift Devices	Thrust		
7***	↓			Down		T/LF or normal thrust	Takeoff thrust	Airspeed
8***	Approach			Down	↓	T/LF or normal thrust	Takeoff thrust plus normal clean-up for go-around	Airspeed
9	Takeoff		↓	Down	Take-off	Take-off thrust	Gear up	Pitch attitude
10	↓	↓	Minimum flap-retract speed	Up	Take-off	Take-off thrust	Retract high lift devices	Airspeed
11	Cruise	h_{0min} and h_{0max}	Speed for level flight	Up	Up	MRT	Idle thrust	Pitch attitude
12				Up	Up	MRT	Actuate deceleration device	

TABLE XIII. Pitch Trim Change Conditions (cont.)

	Flight Phase	Initial Trim Conditions					Configuration Change	Parameter to be held constant
		Altitude	Speed	Landing Gear	High-lift Devices	Thrust		
13				Up	Up	MRT	Maximum augmented thrust	
14			Speed for best range	Up	Up	TLF	Actuate deceleration device	Altitude
15	Aerial Delivery	h_{min}	V_{max}	Up	As required	TLF	Open cargo door	Altitude & Airspeed
16	Aerial Delivery	h_{min}	V_{max}	Up	As required	TLF	Open jump door	Altitude & Airspeed
17	Low Altitude Aerial Delivery	h_{min}	V_{min}	Down	As required	TLF	Drop maximum weight cargo	Altitude & Airspeed

* Throttle setting may be changed during maneuver.

Notes: Auxiliary drag devices are initially retracted, and all details of configuration not specifically mentioned are normal for the Flight Phase.

- If power reduction is permitted in meeting the deceleration requirements established for the mission, actuation of the deceleration device in #12 and #14 shall be accompanied by the allowable power reduction.

** 3 and 4 also shall be investigated for V_{max} and the approach flap shall be changed to landing flap deflection.

*** 5, 7 and 8 also shall be investigated for the landing flap deflection.

3.7

ATMOSPHERIC ENVIRONMENT

This section presents the mean wind and turbulence models to be used for flight control system design. Sections 3.7.1 and 3.7.2 present models for continuous wind phenomena; mean wind and turbulence, and Section 3.7.3 presents the discrete gust model.

For the continuous wind phenomena, wind and turbulence levels are defined by a probability of exceedence and altitude. For the low altitude models (below about 3,000 feet), the probability of exceedence defines a mean wind profile. This wind level then defines the turbulence levels. For high altitude operation (above about 3,000 feet), mean winds are not important for handling qualities so exceedence probabilities directly define turbulence levels and a mean wind model is not used.

The continuous wind phenomena are generated in an earth-reference axis system, and transformed to the body-axis system. The calculation of airspeed is then:

TRANSITIONAL

$$\begin{bmatrix} U_A \\ V_A \\ W_A \end{bmatrix} = \begin{bmatrix} U \\ V \\ W \end{bmatrix} - \begin{bmatrix} U_W \\ V_W \\ W_W \end{bmatrix} - \begin{bmatrix} U_t \\ V_t \\ W_t \end{bmatrix}$$

Body Inertial Velocity Mean Wind Turbulence

ROTATIONAL

$$\begin{bmatrix} P \\ Q \\ R \end{bmatrix} = \begin{bmatrix} P \\ Q \\ R \end{bmatrix} - \begin{bmatrix} P_t \\ Q_t \\ R_t \end{bmatrix}$$

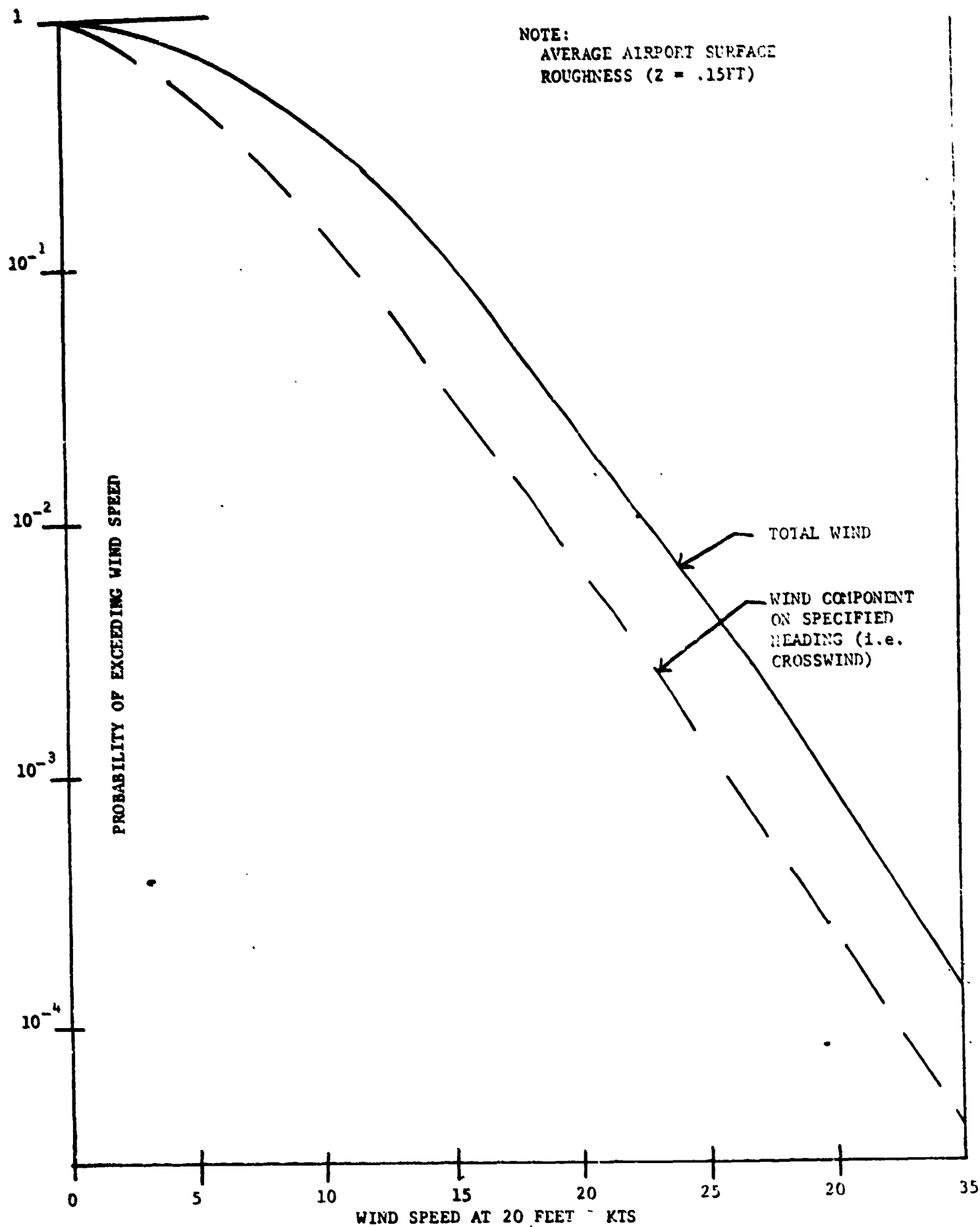
Body Inertial Velocity Turbulence

3.7.1

Mean Wind

The probability of exceeding a wind level at a given altitude is dependent upon surface roughness conditions, z . For average airport conditions, the level of total wind occurring from any direction at 20 feet above the surface is determined from Figure 7/1 for a specified exceedence probability.

The mean wind at any altitude, \bar{V}_W , is defined by the following equation:



$$\bar{V}_v = \left(\bar{V}_{20} \right)_{z=.15} \left[\frac{\left(\bar{V}_{20} \right)_z}{\left(\bar{V}_{20} \right)_{z=.15}} \right] \left[\frac{\bar{V}_h}{\bar{V}_{20}} \right]$$

where

$$\left(\bar{V}_{20} \right)_{z=.15} = \text{Mean wind at 20 ft. reference altitude and surface roughness } z = .15, \text{ from Figure 7/1}$$

$$\frac{\left(\bar{V}_{20} \right)_z}{\left(\bar{V}_{20} \right)_{z=.15}} = \text{Surface roughness correction factor for reference mean wind, from Figure 7/2}$$

$$\frac{\bar{V}_h}{\bar{V}_{20}} = \frac{\ln \left(\frac{h_{cg} + z}{z} \right)}{\ln \left(\frac{20 + z}{z} \right)}$$

h_{cg} = Height of aircraft center of gravity ~ feet.

The surface roughness condition, z , is based on the roughness of the landing field and immediate vicinity. Any roughness is negligible if it lies below a plane extending upwind from the runway with a 1 in 10 slope. Also, any roughness which is more than one mile distant is completely negligible. Based on these considerations and the type of airfield the AMBT will operate from, a $z = 0.15$ ft shall be used. Mean wind profiles for different surface roughness conditions are shown on Figure 7/3 for reference.

Figure 7/1 also presents the exceedence probabilities associated with the level of a wind component in a specific direction (i.e., probability of exceedence for a cross-runway component) measured at twenty feet above the surface. The curve labeled "total wind" is to be used as the wind vector occurring from any direction. At high altitudes the mean winds can be neglected since they do not affect the flying qualities.

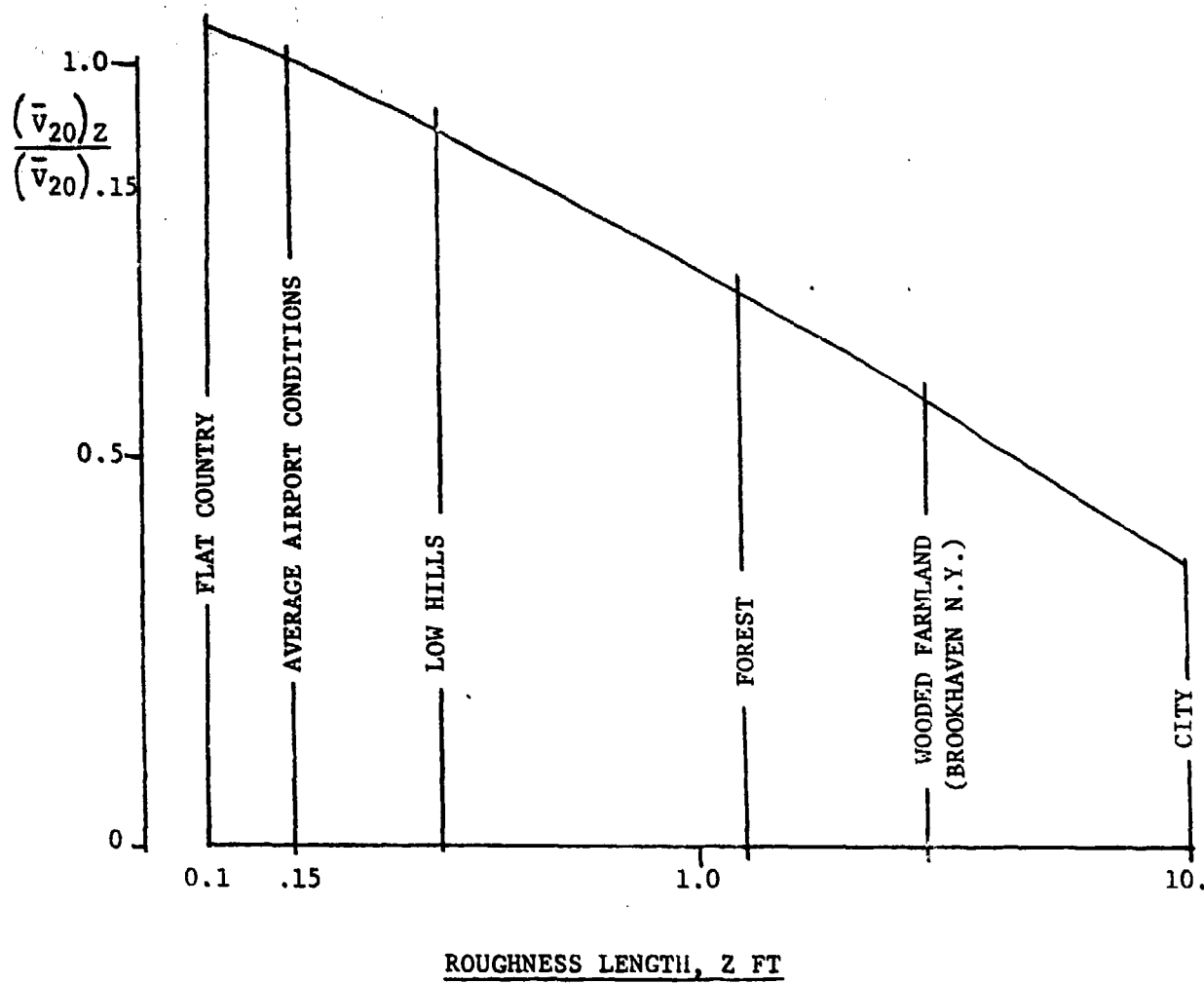
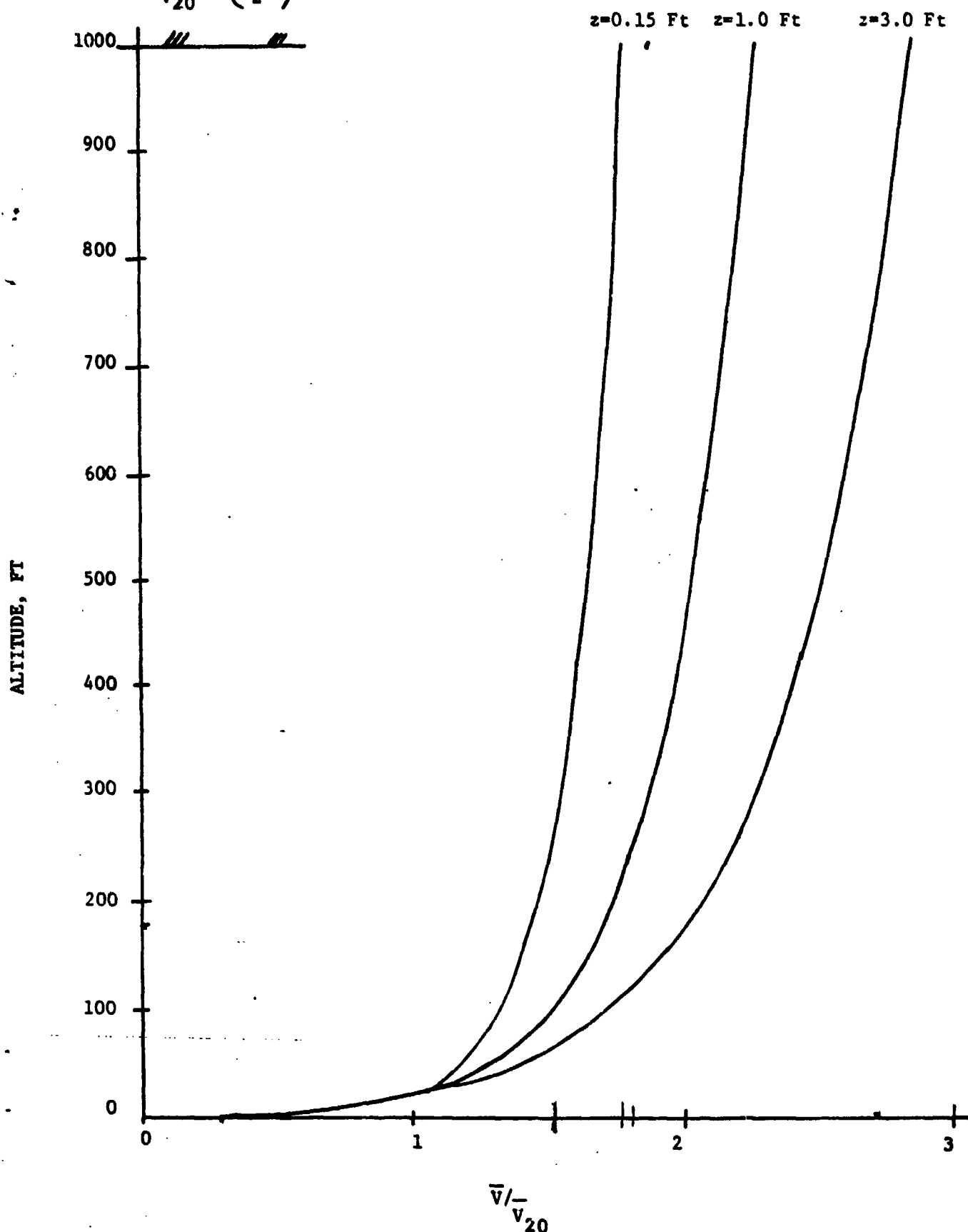


FIGURE 7/2 MEAN WIND SURFACE ROUGHNESS CORRECTION

$$\frac{\bar{V}}{\bar{V}_{20}} = \frac{\ln\left(\frac{1+z}{z}\right)}{\ln\left(\frac{20+z}{z}\right)}$$



MEAN-WIND PROFILES
Figure 7/3
127

3.7.1.1 Transformation of Mean Wind to Body Axes

The mean wind is transformed to body axis components as follows:

$$\begin{bmatrix} U_w \\ V_w \\ W_w \end{bmatrix} = \begin{bmatrix} \cos(\psi - \psi_w) \cos \Theta \\ \cos(\psi - \psi_w) \sin \Theta \sin \phi - \sin(\psi - \psi_w) \cos \phi \\ \cos(\psi - \psi_w) \sin \Theta \cos \phi + \sin(\psi - \psi_w) \sin \phi \end{bmatrix} \bar{V}_w$$

3.7.2

Turbulence

The turbulence model consists of turbulence levels, turbulence scales (representing eddy sizes), and power spectra which define the distribution of turbulence power with frequency. Turbulence spectra, levels, and scales are not generally aligned to the airplane's axis system, so transformations must be executed before applying turbulence components.

3.7.2.1 Turbulence Filter

Random turbulence velocities are generated from filtered white noise. The filters required to produce the velocity components, which have a Von Karman power spectrum, are defined by the following transfer functions for a digital computer.

$$F_{u_t}(s) = \sigma_u \sqrt{\frac{2L_u}{\Delta T \pi V_{RW}}} \frac{(1 + 0.25 \frac{L_u}{V_{RW}} s)}{(1 + 1.19 \frac{L_u}{V_{RW}} s)(1 + 0.167 \frac{L_u}{V_{RW}} s)}$$

$$F_{v_t}(s) = \sigma_v \sqrt{\frac{L_v}{\Delta T \pi V_{RW}}} \frac{(1 + 2.618 \frac{L_v}{V_{RW}} s)(1 + 0.1298 \frac{L_v}{V_{RW}} s)}{(1 + 2.083 \frac{L_v}{V_{RW}} s)(1 + 0.823 \frac{L_v}{V_{RW}} s)(1 + 0.0893 \frac{L_v}{V_{RW}} s)}$$

$$F_{w_t}(s) = \sigma_w \sqrt{\frac{L_w}{\Delta T \pi V_{RW}}} \frac{(1 + 2.618 \frac{L_w}{V_{RW}} s)(1 + 0.1298 \frac{L_w}{V_{RW}} s)}{(1 + 2.083 \frac{L_w}{V_{RW}} s)(1 + 0.823 \frac{L_w}{V_{RW}} s)(1 + 0.0893 \frac{L_w}{V_{RW}} s)}$$

where

- (1) These filters match the Von Karman PSD's for $\omega < 10$ rad/sec

(2) ΔT : computer frame time used for turbulence generation.

$$(3) V_{RM} = \sqrt{U_A^2 + V_A^2 + W_A^2}$$

(4) Use unity RMS white noise

If an analog white noise source is used, then the filters are given by the following relationships:

$$G_{u_t}(s) = \sqrt{\frac{\Delta T}{2\pi}} F_{u_t}(s)$$

$$G_{v_t}(s) = \sqrt{\frac{\Delta T}{2\pi}} F_{v_t}(s)$$

$$G_{w_t}(s) = \sqrt{\frac{\Delta T}{2\pi}} F_{w_t}(s)$$

With the analog source, unity spectrum amplitude white noise must be used.

3.7.2.2 Turbulence Levels

Low Altitude Turbulence ($h < 3,000$ feet)

The root mean square level of the turbulence component acting perpendicular to the earth, σ_w , is derived from the mean wind speed at 20 feet above the surface from:

$$\sigma_w = .52 \left[\frac{\bar{V}_{20}}{\ln \left(\frac{20+z}{z} \right)} - \frac{h_z g}{600} \right] \geq 0 \quad (\text{Figure 7/4})$$

R.M.S. levels of horizontal components of turbulence are found by using Figure 7.5.

High Altitude Turbulence ($h > 3,000$ feet)

For high altitudes, the levels of turbulence components oriented in any direction are equal: $\sigma_u = \sigma_v = \sigma_w$. The levels of high altitude turbulence (including storm turbulence) are determined from exceedence probabilities using Figure 7.6.

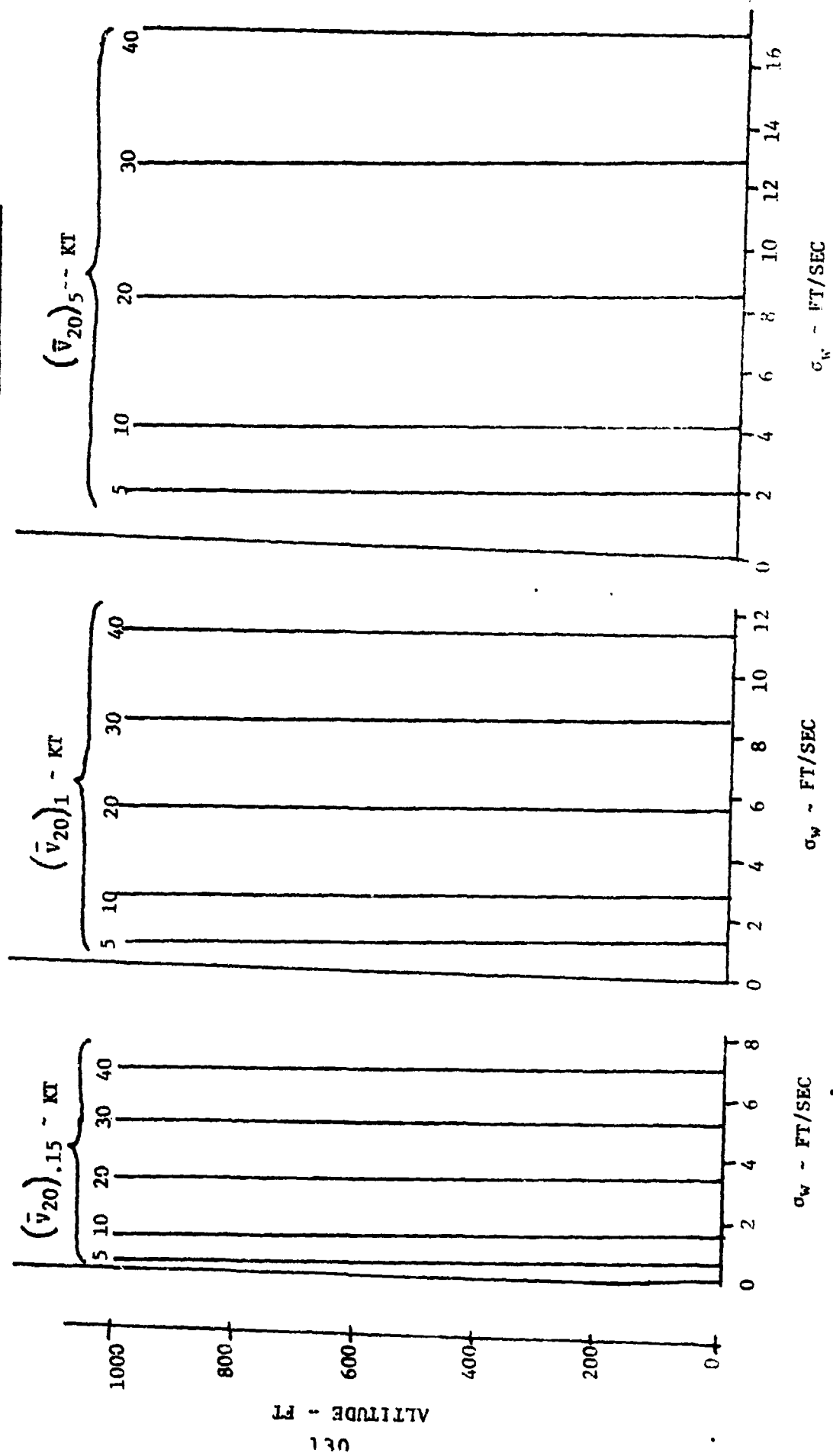
3.7.2.3 Integral Scales Lengths

Integral scales for turbulence at all altitudes are determined from Figure 7/7 and altitude. Note that $L_u = L_v = L_w$ for $h_{cg} \geq 1000$ ft.

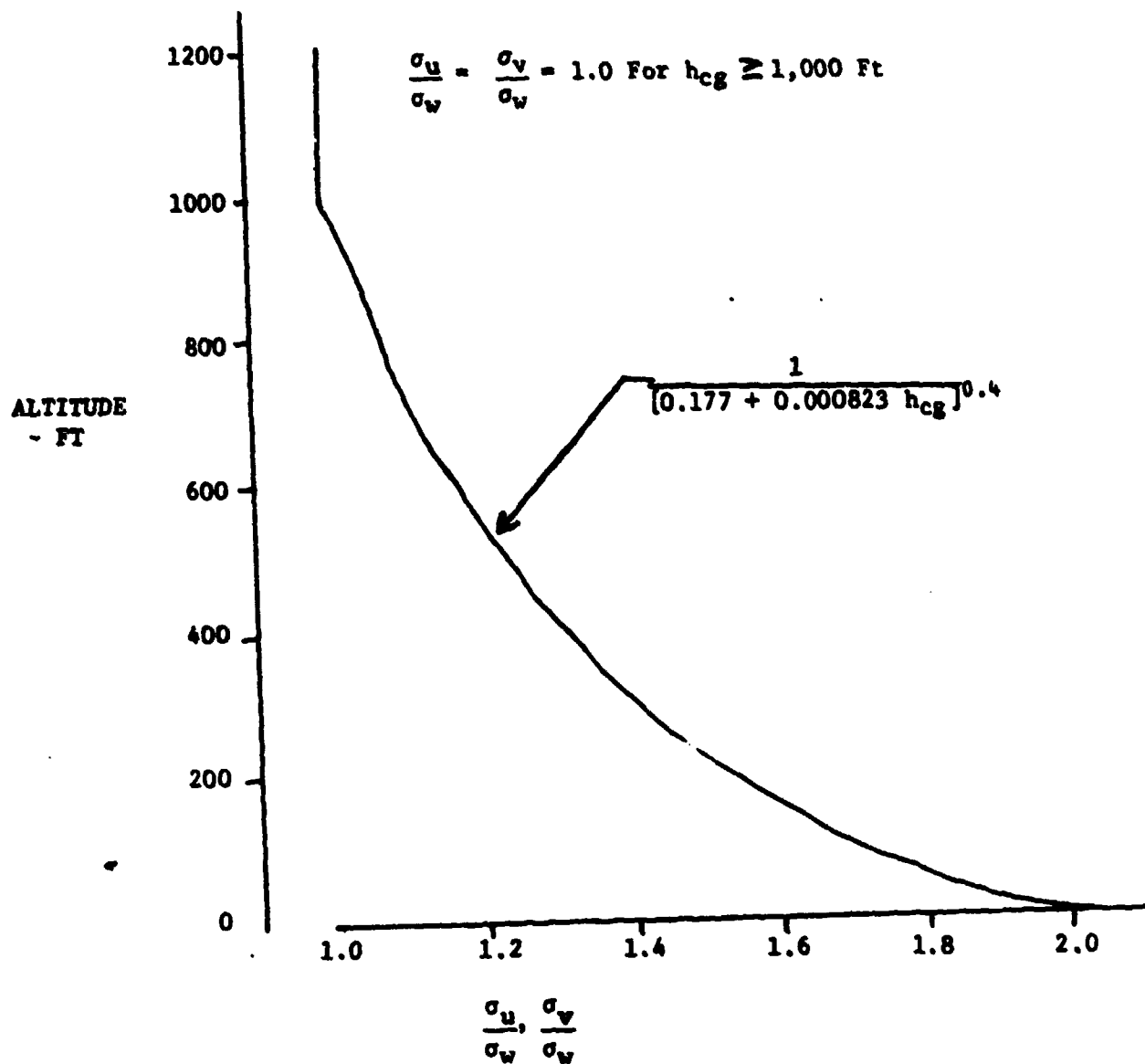
$Z = 0.15 \text{ FT}$

$Z = 1.0 \text{ FT}$

$Z = 3.0 \text{ FT}$



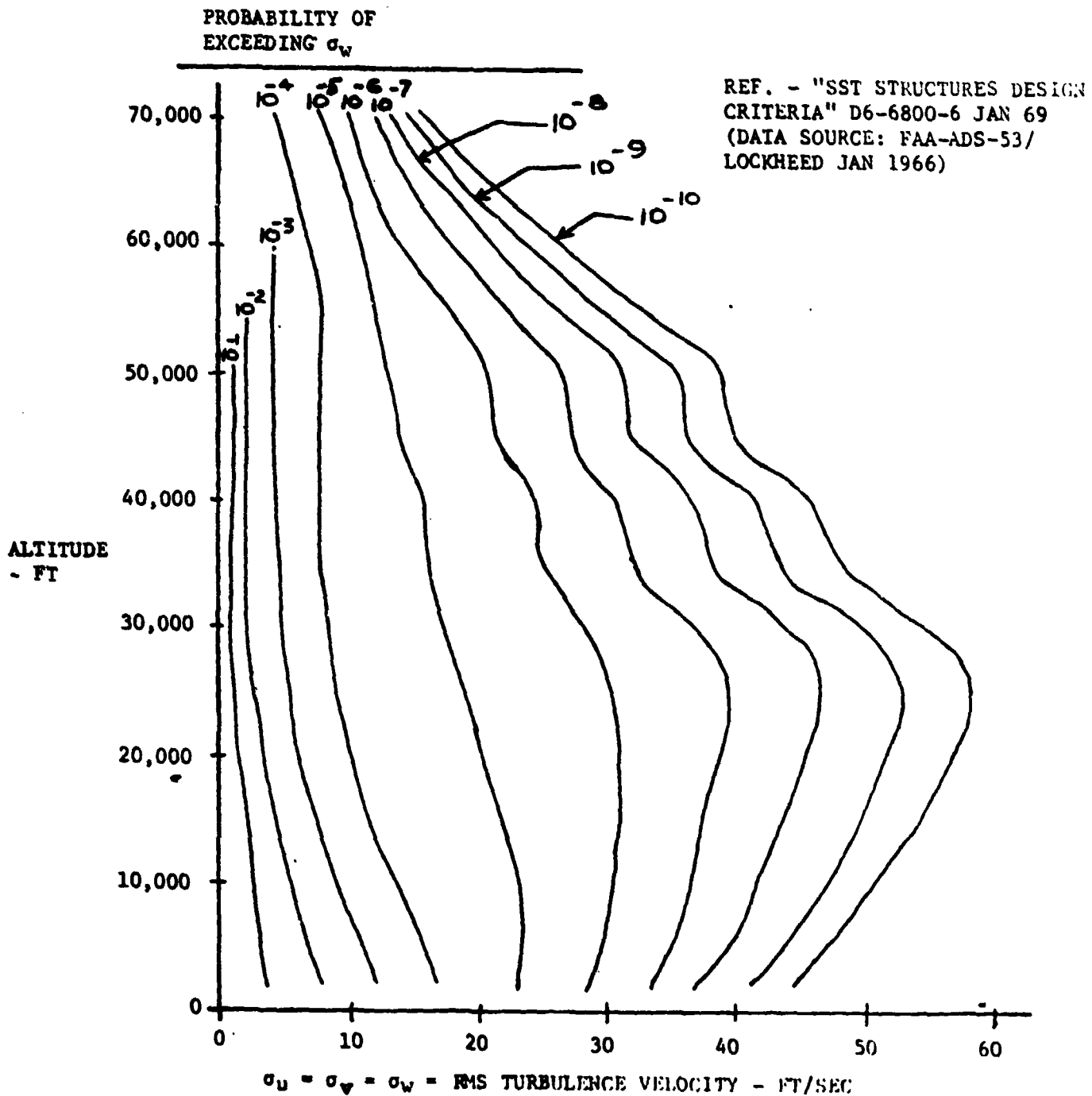
Low-Altitude Vertical Turbulence Component
Figure 7/4



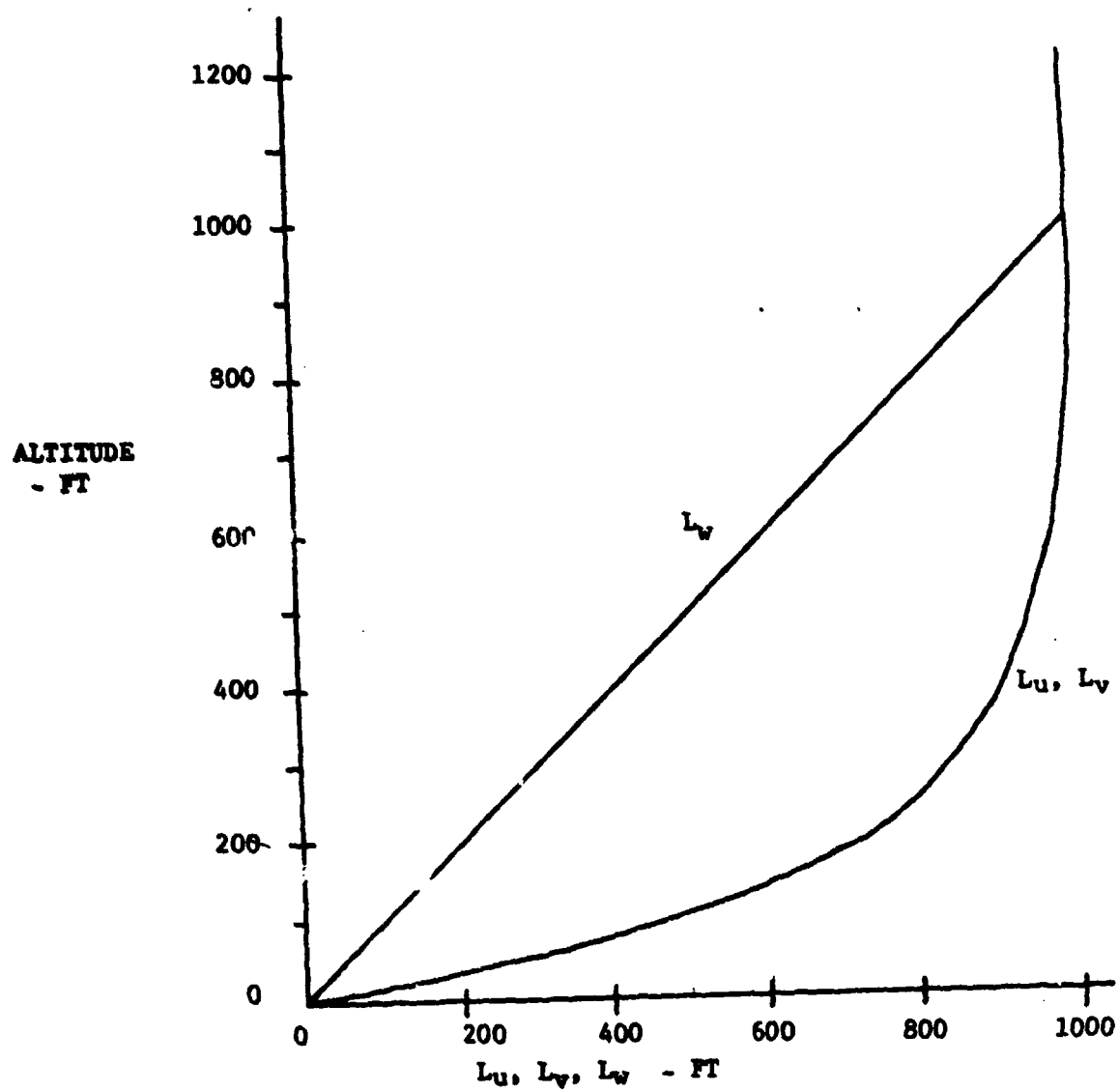
Horizontal Turbulence Components
Figure 7/5

PROBABILITY OF EXCEEDING $\sigma_u = \sigma_v = \sigma_w$
DURING ROUTINE OPERATIONS

INCLUDES STORM TURBULENCE



High Altitude Turbulence Levels; Figure 7/6



Turbulence Scale Lengths For All Altitudes; Figure 7/7

3.7.2.4 Turbulence Velocities

The random turbulence velocities are generated as shown in Figure 7/8. Note that both translational and rotational velocities are produced.

3.7.2.5 Transformation to Body Axes

For low altitude, the W_tE component refers to the component perpendicular to the earth while the U_tE and V_tE components are aligned parallel and perpendicular to the airplane's relative velocity vector projected onto the plane of the earth. The transformations required to obtain body axes components at low altitudes are approximated by:

$$\begin{bmatrix} U_t \\ V_t \\ W_t \end{bmatrix} = \begin{bmatrix} \cos\Delta\psi \cos\theta & \sin\Delta\psi \cos\theta & -\sin\theta \\ \cos\Delta\psi \sin\theta \sin\phi & \sin\Delta\psi \sin\theta \sin\phi & \cos\theta \sin\phi \\ -\sin\Delta\psi \cos\phi & +\cos\Delta\psi \cos\phi & \\ \cos\Delta\psi \sin\theta \cos\phi & \sin\Delta\psi \sin\theta \cos\phi & \cos\theta \cos\phi \\ +\sin\Delta\psi \sin\phi & -\cos\Delta\psi \sin\phi & \end{bmatrix} \begin{bmatrix} U_{tE} \\ V_{tE} \\ W_{tE} \end{bmatrix}$$

Body Axes
Turbulence
Components

Low-Altitude Turbulence
Transformation Matrix

Earth-
Oriented
Turbulence
Components

where

$\Delta\psi$ = angle from projection of airspeed vector on plane of earth to X body axis projection on plane of earth.

$$= -\tan^{-1}\left(\frac{V_{Ap}}{U_{Ap}}\right)$$

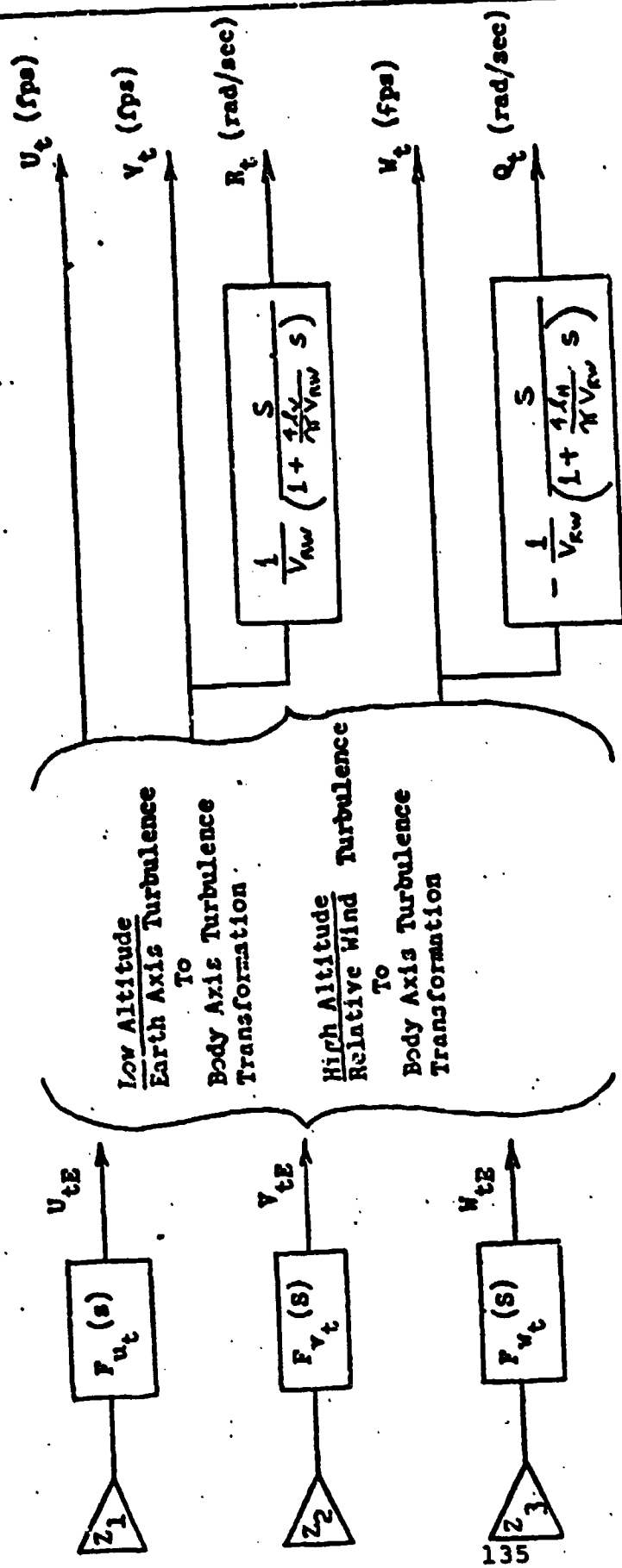
$$U_{Ap} = [\cos\alpha \cos\beta \cos\theta + \sin\beta \sin\theta \sin\phi + \sin\alpha \cos\beta \sin\theta \cos\phi]V_{RW}$$

$$V_{Ap} = [\sin\beta \cos\theta - \sin\alpha \cos\beta \sin\theta]V_{RW}$$

$$V_{RW} = \sqrt{U_A^2 + V_A^2 + W_A^2}$$

At high altitude the turbulence components are aligned with the airplane relative velocity vector. The transformation to body axes is given by:

FIGURE 7/8 RANDOM TURBULENCE VELOCITIES



Z_1 : Independent, digital, Gaussian, unit RMS white noise source. For analog white noise source use unity spectrum amplitude.

$F_t(s)$: Turbulence filter transfer function. For analog computer use $G_t(s)$

L_v : Vertical tail moment arm, center of gravity to vertical tail aerodynamic center.

L_H : Horizontal tail moment arm, center of gravity to horizontal tail aerodynamic center.

$$\begin{bmatrix} u_t \\ v_t \\ w_t \end{bmatrix} = \begin{bmatrix} \cos \alpha \sin \beta & -\cos \alpha \sin \beta & -\sin \alpha \\ \sin \beta & \cos \beta & 0 \\ \sin \alpha \cos \beta & -\sin \alpha \sin \beta & \cos \beta \end{bmatrix} \begin{bmatrix} u_{tE} \\ v_{tE} \\ w_{tE} \end{bmatrix}$$

Body Axes Turbulence Components High-Altitude Turbulence Transformation Matrix Relative Wind Oriented Turbulence Components

3.7.3 Discrete Gust Analysis

The discrete gust model described below is to be used in handling qualities analysis only.

The aircraft shall be controllable (within structural limits) when submitted to the following discrete gusts. A conservative estimate of the most extreme turbulence to be encountered during the fleet life-time shall be used.

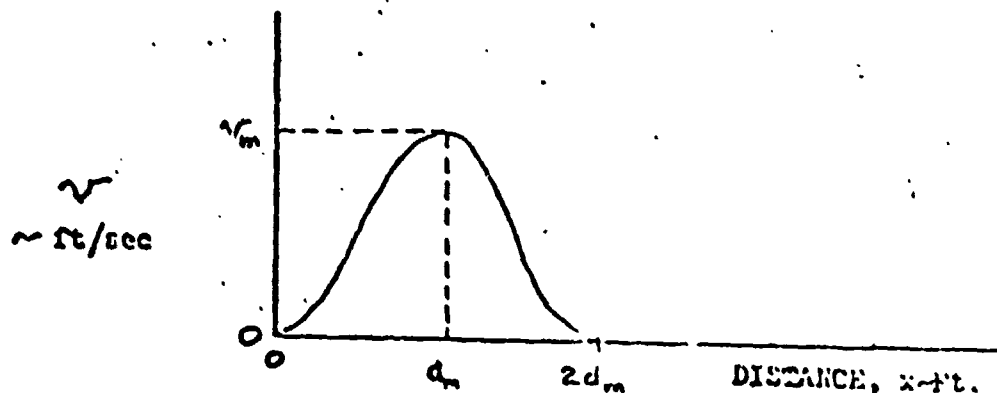
The discrete gust model may be used for any of the three gust-velocity components. The discrete gust has the "1 - cosine" shape:

$$v = \begin{cases} 0 & , x < 0 \\ \frac{v_m}{2} \left(1 - \cos \frac{\pi x}{d_m} \right) & , 0 \leq x \leq 2d_m \\ 0 & , x > 2d_m \end{cases}$$

where

$$d_m = d_x, d_y, \text{ or } d_z$$

$$v_m = v_x, v_y, \text{ or } v_z$$



Several values of d_1 shall be used, each chosen so that the gust is tuned to the natural frequencies of the airplane and its flight control system. The magnitude v_m shall then be chosen from Figure 7/9.

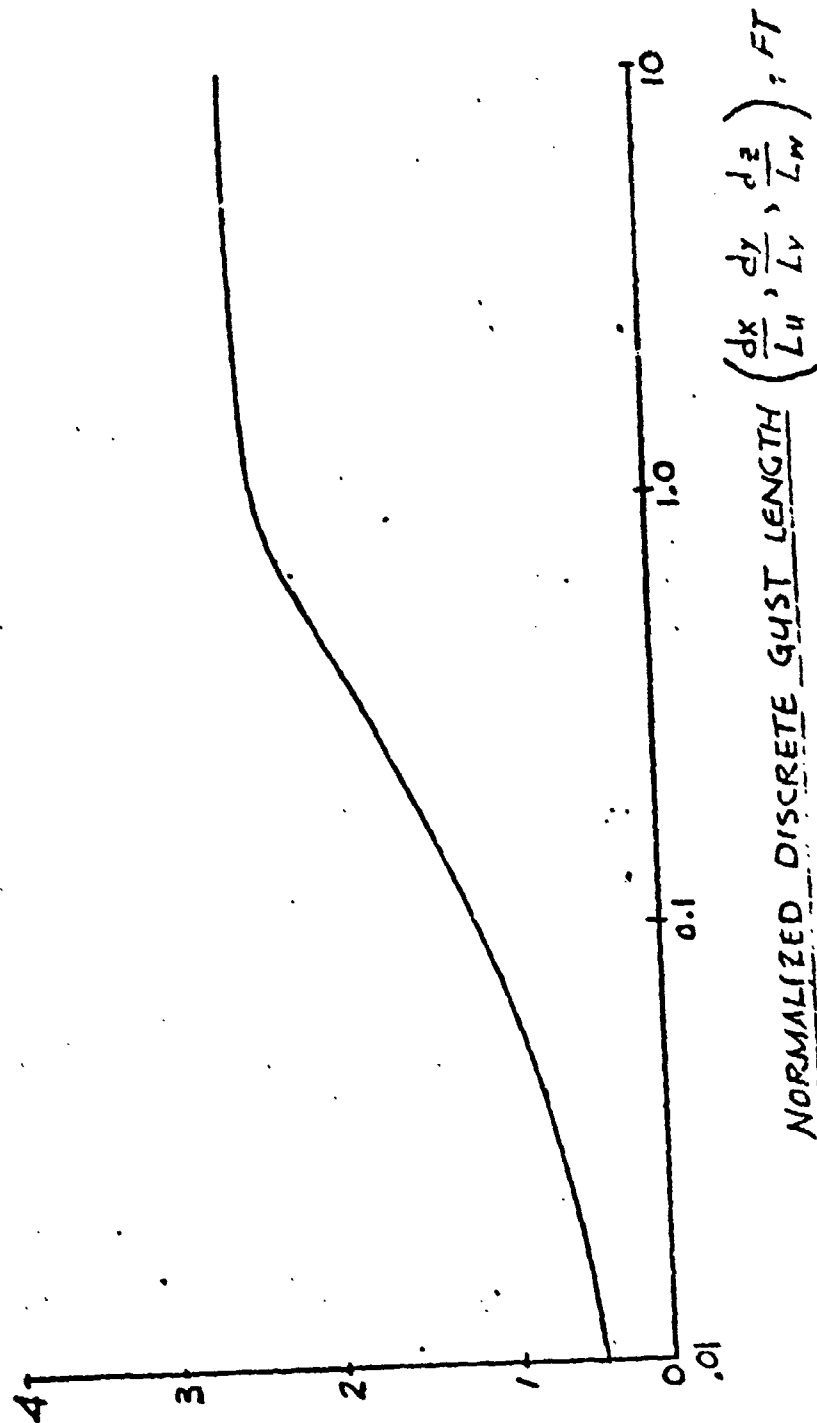
L_u , L_v , and L_w are obtained from Figure 7/7

σ_u , σ_v , and σ_w are given in Section 3.7.2.2

$$\text{NORMALIZED Gust ALTERNATIVE} = \left(\frac{V_x}{V_y}, \frac{V_z}{V_y}, \frac{V_z}{V_x} \right), \frac{V_z}{V_y}$$

Magnitude of Discrete Cust

REF. MIL-F-8785B (ASG), FLYING QUALITIES FOR PIVOTED AIRPLANE'S



5. Preparation for Delivery.

5.1 Section 3 is not applicable to this specification.

6. Notes.

6.1 Intended Use. This specification contains the flying qualities requirements for the C-17A and forms one of the bases for determination by the procuring activity of airplane acceptability. The specification serves as design requirements and as criteria for use in stability and control calculations, analysis of wind-tunnel test results, flying qualities simulation tests, and flight testing and evaluation. The requirements are intended to assure adequate flying qualities regardless of design implementation or flight control system mechanization. To the extent possible, this specification should be met by providing an inherently good basic airframe. Where that is not entirely feasible, or where inordinate penalties would result, a mechanism is provided herein to assure that the flight safety, flying qualities and reliability aspects of dependence on stability augmentation and other forms of system complication will be considered fully.

6.2 Definitions. Terms and symbols used throughout this specification are defined as follows:

6.2.1 General.

S	- wing area
s	- Laplace operator
q	- dynamic pressure
MSL	- mean sea level
T_2	- time to double amplitude; $T_2 = \frac{-.693}{\zeta \omega_n}$ for oscillations. $T_2 = -.693\tau$ for first-order divergences.
Airplane Normal States	- the nomenclature and format of table XV shall be used in defining the Airplane Normal States (3.1.6.1)
Service ceiling	- altitude at a given airspeed at which the rate of climb is 100 ft/min at stated weight and engine thrust
Combat ceiling	- altitude at a given airspeed at which rate of climb is 500 ft/min at stated weight and engine thrust
Cruising ceiling	- altitude at a given airspeed at which rate of climb is 300 ft/min at NRT at stated weight.
h_{max}	- maximum service altitude (defined in 3.1.8.3)
$h_{o max}$	- maximum operational altitude (3.1.7)

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$h_{o_{min}}$

- minimum operational altitude (3.1.7)

c.g.

- airplane center of gravity

6.2.2 Speeds

Equivalent airspeed

- true airspeed multiplied by $\sqrt{\sigma}$, where σ is the ratio of free-stream density at the given altitude to standard sea-level air density

Calibrated airspeed

- Airspeed-indicator reading corrected for position and instrument error but not for compressibility

Refusal speed

- the maximum speed to which the airplane can accelerate and then stop in the available runway length

M

- Mach number

V

- airspeed (where appropriate, V may be replaced by M in this specification), along the flight path

V_S

- stall speed (equivalent airspeed), see paragraph 3.1.9.2.

$V_S(X)$, $V_{min}(X)$,
 $V_{max}(X)$

- short-hand notation for the speeds V_S , V_{min} , V_{max} for a given configuration, weight, center-of-gravity position, and external store combination associated with Flight Phase X. For example, the designation $V_{max}(TO)$ is used in 3.2.3.3.2 to emphasize that the speed intended (for the weight, center of gravity, under consideration)

TABLE XV. Airplane Normal States

Flight Phase	Weight	C.G.	Inertia	Thrust	High Lift Devices	Landing Gear	Speed Brakes	Cargo Doors	Stability Augmentation (Pitch, Roll, Yaw) Control	Automatic Speed Control
Takeoff										
Climb										
Cruise										
Descent										
Emergency Descent										
Emergency Deceleration										
Approach										
Go-Around										
Landing										
Aerial Delivery										
Aerial Recovery										
Aerial Receiver										
Aerial Terrain Following										
Stage Formation Flying										
Altitude										
Aerial Delivery										
Zoom Climb										

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is V_{max} for the configuration associated with the takeoff Flight Phase. This is necessary to avoid confusion, since the configuration and Flight Phase change from takeoff to climb during the maneuver.

V_{trim}	- trim speed
V_{end}	- speed for maximum endurance
$V_{L/D}$	- speed for maximum lift-to-drag ratio
$V_{R/C}$	- speed for maximum rate of climb
V_{range}	- speed for maximum range in zero wind conditions
V_{NRT}	- high speed, level flight, normal rated thrust
V_{MRT}	- high speed, level flight, military rated thrust
V_{MAT}	- high speed, level flight, maximum augmented thrust
V_{max}	- maximum service speed (defined in 3.1.8.1)
V_{min}	- minimum service speed (defined in 3.1.8.2)
V_{Omax}	- maximum operational speed
V_{Omin}	- minimum operational speed

6.2.3 Thrust

TLF	- thrust for level flight
NRT	- normal rated thrust, which is the maximum thrust at which the engine can be operated continuously
MRT	- military rated thrust, which is the maximum thrust at which the engine can be operated for a specified period

MAT

- maximum augmented thrust: maximum thrust, augmented by all means available for the Flight Phase

Takeoff thrust

- maximum thrust available for takeoff

6.2.4 Control parameters

Elevator, aileron,
rudder controls

- The stick or wheel and rudder pedals manipulated by the pilot to produce pitching, rolling, and yawing moments respectively; the cockpit controls

Elevator control
force

- Component of applied force, exerted by the pilot on the cockpit control, in or parallel to the plane of symmetry, acting at the center of the stick grip or wheel in a direction perpendicular to a line between the center of the stick grip or wheel and the stick or control column pivot

Aileron control
force

- For a stick control, the component of control force exerted by the pilot in a plane perpendicular to the plane of symmetry, acting at the center of the stick grip in a direction perpendicular to a line between the center of the stick grip and the stick pivot. For a wheel control, the total moment applied by the pilot about the wheel axis in the plane of the wheel, divided by the average radius from the wheel pivot to the pilot's grip.

Rudder pedal force

- Difference of push-force components of forces exerted by the pilot on the rudder pedals, lying in planes parallel to the plane of symmetry, measured perpendicular to the pedals at the normal point of application of the pilot's instep on the respective rudder pedals

Control surface

- A device such as an external surface which is positioned by a cockpit control or stability augmentation system to produce aerodynamic or jet-reaction type forces for controlling the attitude of the airplane. As used in this specification the elevator surface, aileron surface, and rudder surface are the control surfaces or devices which are controlled by the stick or wheel and rudder pedals, and automatically by stability augmentation systems.

**Direct normal
force control**

- A device producing direct normal force for the primary purpose of controlling the flight path of the airplane. Direct normal force control is the descriptive title given to the concept of directly modulating the normal force on an airplane by changing its lifting capabilities at a constant angle of attack and constant airspeed or by controlling the normal force component of such items as jet exhausts.

Control power

- Effectiveness of control surfaces in applying forces or moments to an airplane. For example, 50% of available aileron control power is 50% of the maximum rolling moment that is available to the pilot with allowable aileron control force.

6.2.5 Longitudinal parameters

ζ_{sp}

- damping ratio of the short-period oscillation

ω_{nsp}

- undamped natural frequency of the short-period oscillation

ζ_p

- damping ratio of the phugoid oscillation

ω_{np}

- undamped natural frequency of the phugoid oscillation

n

- normal acceleration or normal load factor, measured at the c.g.

n_L

- symmetrical flight limit load factor for a given Airplane Normal State, based on structural considerations

n_{max}, n_{min}

- maximum and minimum Service load factors

$n(+), n(-)$

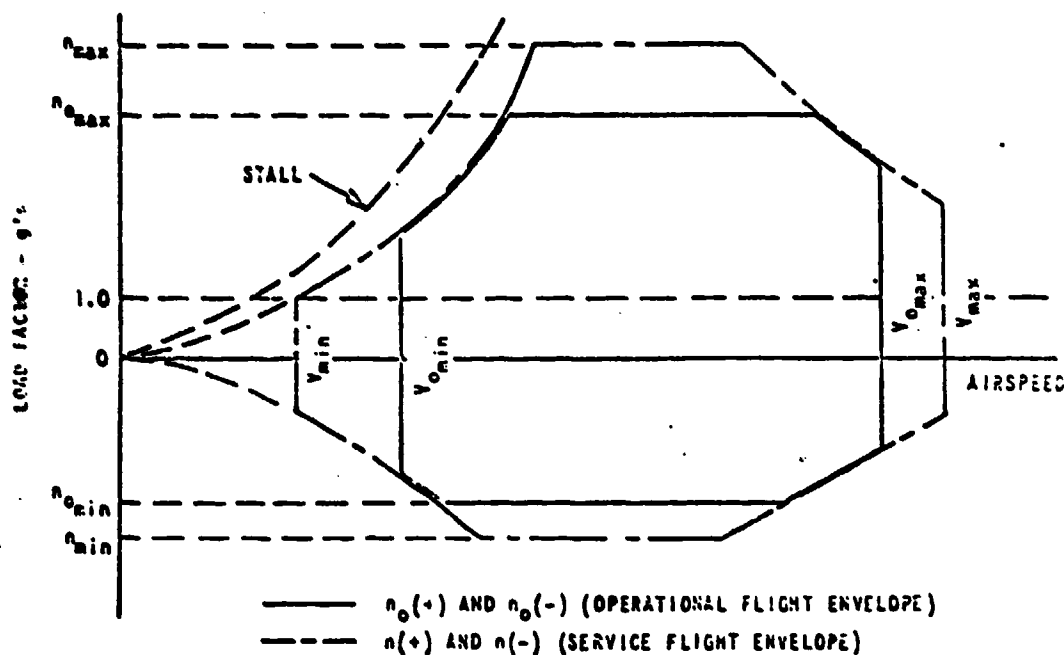
- for a given altitude, the upper and lower boundaries of n in the V-n diagrams depicting the Service Flight Envelope

$n_{c\max}, n_{c\min}$

- maximum and minimum Operational load factors

$n_o(+), n_o(-)$

- for a given altitude, the upper and lower boundaries of n in the V-n diagrams depicting the Operational Flight Envelope



α

- angle of attack; the angle in the plane of symmetry between the fuselage reference line and the tangent to the flight path at the airplane center of gravity

$n_{c\max}, n_{c\min}$ - Maximum and minimum load factors required to be generated by use of the primary longitudinal control surface alone.

α_s

- the stall angle of attack at constant speed for the configuration, weight, center of gravity position and external-store combination associated with a given Airplane Normal State; defined as the lowest of the following:

- a. Angle of attack for the highest steady load factor, normal to the flight path, that can be attained at a given speed or Mach number
- b. Angle of attack, for a given speed or Mach number, at which uncommanded pitching, rolling, or yawing occurs (3.4.2.1.2).
- c. Angle of attack, for a given speed or Mach number, at which intolerable buffeting is encountered.
- d. An arbitrary angle of attack allowed by 3.1.9.2.

C_{Lstall}

- lift coefficient at α_s defined above.

n/a

- the steady-state normal acceleration change per unit change in angle of attack for an incremental elevator deflection at constant speed (airspeed and Mach number)

F_s/n

- gradient of steady-state elevator control force versus n at constant speed (3.2.2.2.1)

γ

- climb angle, positive for climbing flight

$$\gamma = \sin^{-1} \frac{\text{Vertical speed}}{\text{True airspeed}}$$

L

- aerodynamic lift plus thrust component, normal to the flight path

6.2.6 Lateral-directional parameters

δ_{AS}

- displacement of the aileron control stick or wheel along its path

τ_R

- first-order roll mode time constant, positive for stable mode

τ_S

- first-order spiral mode time constant, positive for stable mode

λ_R

- $-1/\tau_R$

λ_S

- $-1/\tau_S$

ω_ϕ

- undamped natural frequency of numerator quadratic of ϕ/δ_{AS} transfer function

- damping ratio of numerator quadratic of ϕ/δ_{AS} transfer function
- undamped natural frequency of the Dutch roll oscillation
- damping ratio of the Dutch roll oscillation
- damped period of the Dutch roll, $T_d = \frac{2\pi}{\omega_{nd} \sqrt{1-\zeta_d^2}}$
- bank angle measured in the y-z plane, between the y-axis and the horizontal (6.2.1)
- bank angle change in time t , in response to control deflection of the form given in 3.3.4
- roll rate about the x-axis (6.2.1)
- a measure of the ratio of the oscillatory component of roll rate to the average component of roll rate following a rudder-pedals-free step aileron control command:

$$\zeta_d \leq 0.2: \frac{p_{osc}}{p_{AV}} = \frac{p_1 + p_3 - 2p_2}{p_1 + p_3 + 2p_2}$$

$$\zeta_d > 0.2: \frac{p_{osc}}{p_{AV}} = \frac{p_1 - p_2}{p_1 + p_2}$$

where p_1 , p_2 and p_3 are roll rates at the first, second and third peaks, respectively.

- a measure of the ratio of the oscillatory component of bank angle to the average component of bank angle following a rudder-pedals-free impulse aileron control command:

$$\zeta_d \leq 0.2: \frac{\phi_{osc}}{\phi_{AV}} = \frac{\phi_1 + \phi_3 - 2\phi_2}{\phi_1 + \phi_3 + 2\phi_2}$$

$$\zeta_d > 0.2: \frac{\phi_{osc}}{\phi_{AV}} = \frac{\phi_1 - \phi_2}{\phi_1 + \phi_2}$$

where ϕ_1 , ϕ_2 and ϕ_3 are bank angles at the first, second and third peaks, respectively.

β

- sideslip angle at the center of gravity, angle between undisturbed flow and plane of symmetry. Positive, or right, sideslip corresponds to incident flow approaching from the right side of the plane of symmetry.

$\Delta\beta_{\max}$

- maximum change in sideslip occurring within 2 seconds or one half-period of the Dutch roll, whichever is greater, for a step wheel-control command.

k

- ratio of "commanded roll performance" to "applicable roll performance requirement" of 3.3.4 or 3.3.4.1, where:

- "Applicable roll performance requirement", (ϕ_r) requirement, is determined from 3.3.4 and 3.3.4.1 for the Class, Flight Phase Category and Level under consideration.
- "Commanded roll performance", (ϕ_c) command, is the bank angle attained in the stated time for a given step aileron command with rudder pedals employed as specified in 3.3.4 and 3.3.4.1

$$k = \frac{(\phi_c) \text{ command}}{(\phi_r) \text{ requirement}}$$

$t_{n\beta}$

- time for the Dutch roll oscillation in the sideslip response to reach the n^{th} local maximum for a right step or pulse aileron-control command, or the n^{th} local minimum for a left command. In the event a step control input cannot be accomplished, the control shall be moved as abruptly as practical and, for purposes of this definition, time shall be measured from the instant the cockpit control deflection passes through half the amplitude of the command value. For pulse inputs, time shall be measured from a point halfway through the duration of the pulse.

ψ_β - phase angle expressed as a lag for a cosine representation of the Dutch roll oscillation in sideslip, where

$$\psi_\beta = -\frac{360}{t_d} t_{n\beta} + (n-1)360(\text{degrees})$$

where n as in $t_{n\beta}$ above

$\angle \frac{p}{\beta}$ - at any angle between roll rate and sideslip in the free Dutch roll oscillation. Angle is positive when p leads β by an angle between 0 and 180°

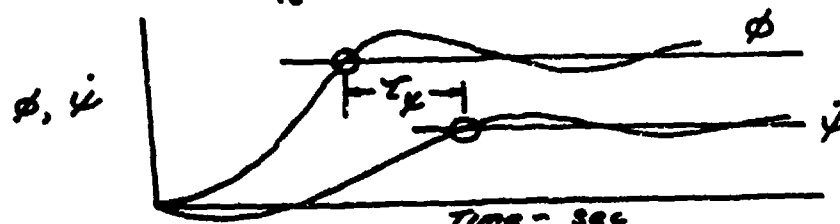
$\left| \frac{\phi}{\beta} \right|_d$ - at any instant, the ratio of amplitudes of the bank-angle and sideslip-angle envelopes in the Dutch roll mode

Since several oscillations of the Dutch roll are required to measure these parameters, and since for proper identification large roll rates and bank angle changes must generally be avoided, for flight test, step aileron inputs should generally be small. It should be noted that since ψ_β is the phase angle of the Dutch roll component of sideslip, care must be taken to select a peak far enough downstream that the position of the peak is not influenced by the roll mode. In practice, peaks occurring one or two roll mode time constants after the aileron input will be relatively undistorted. Care must also be taken when there is ramping of the sideslip trace, since ramping will displace the position of a peak of the trace from the corresponding peak of the Dutch roll component. In practice, the peaks of the Dutch roll component of sideslip are located by first drawing a line through the ramping portion of the sideslip trace and then noting the time at which the vertical distance between the line and the sideslip trace is the greatest.

- heading response time delay for a commanded step bank angle change, defined by the following transfer function and time history:

$\phi(s)$ - commanded step bank angle change

$$\psi(s) = \frac{1}{V_s} e^{-\tau_p s} \phi(s)$$



6.2.7 Atmospheric disturbances parameters

- Ω - spatial (reduced) frequency (radians per foot)
- ω - temporal frequency (radians per second),
where $\omega = \Omega V$
- u_t - random gust velocity along the x body axis (feet per second)
- v_t - random gust velocity along the y body axis (feet per second)
- w_t - random gust velocity along the z body axis (feet per second)

- σ - root-mean-square gust intensity, where

$$\sigma^2 = \int_0^\infty \Phi(\Omega) d\Omega = \int_0^\infty \phi(\omega) d\omega$$

- σ_u - root-mean-square intensity of u_g
- σ_v - root-mean-square intensity of v_g
- σ_w - root-mean-square intensity of w_g
- L_u - scale for u_g (feet)
- L_v - scale for v_g (feet)
- L_w - scale for w_g (feet)
- $\phi u_g(\Omega)$ - spectrum for u_g , where $\phi u_g(\Omega) = V \phi_{u_g}(\omega)$
- $\phi v_g(\Omega)$ - spectrum for v_g , where $\phi v_g(\Omega) = V \phi_{v_g}(\omega)$

$\phi_w(\Omega)$

- spectrum for w_g , where $\phi_w(\Omega) = V\phi_w(\omega)$

v_m

- generalized discrete gust velocity, positive along the positive airplane body axes, $m = x, y, z$ (feet per second)

d_m

- generalized discrete gust length (always positive)
 $m = x, y, z$ (feet)

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